Draft

Report for Illinois River Watershed and Tenkiller Ferry Lake Nutrient TMDLs

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List of Acronyms and Abbreviations

Chl-*a*	Chlorophyll-*a*
COD	Chemical Oxygen Demand
COE	United States Army Corps of Engineers
ODEQ	Oklahoma Department of Environmental Quality
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
DSLLC	Dynamic Solutions, LLC
EFDC	Environmental Fluid Dynamics Code
EPA	Environmental Protection Agency
HSPF	Hydrologic Simulation Program - Fortran
HUC	Hydrologic Unit Code
LPOC	Labile particulate organic carbon
LPON	Labile particulate organic nitrogen
LPOP	Labile particulate organic phosphorus
NLW	Nutrient Limited Waterbody
NPS	Nonpoint Source
OCC	Oklahoma Conservation Commission
OWRB	Oklahoma Water Resources Board
POM	Particulate Organic Matter
PON	Particulate Organic Nitrogen
POP	Particulate Organic Phosphorus
RMS	Root Mean Square
RMSE	Root Mean Square Error
RPOC	Refractory particulate organic carbon
RPON	Refractory particulate organic nitrogen
RPOP	Refractory particulate organic phosphorus
SOD	Sediment Oxygen Demand
TKN	Total Kjedhal Nitrogen (Total Organic Nitrogen + Ammonia-N)
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TON	Total Organic Nitrogen
TOP	Total Organic Phosphorus
TP	Total Phosphorus
TPO4	Total Phosphate
TSI	Trophic State Index
TSS	Total Suspended Solids
USGS	United States Geological Survey

EXECUTIVE SUMMARY

The Illinois River is a multijurisdictional tributary of the Arkansas River, approximately 100 miles (160) km) long, between the States of Arkansas and Oklahoma. The Illinois River begins in the Ozark Mountains in the northwest corner of Arkansas (Washington County) and flows west into northeast Oklahoma. Once the Illinois River enters Oklahoma, it then flows southwest and south through the mountains of eastern Oklahoma into Tenkiller Ferry Lake. Illinois River was identified to be impaired by higher levels of phosphorous. The nutrient pollution is one of America's most widespread, costly and challenging environmental problems, and is caused by excess nitrogen and phosphorus in the air and water. Phosphorus levels in the Illinois River can be caused by various types of city and industrial discharges as well as nonpoint source run-off. The downstream impacts to Lake Tenkiller may include 'algal blooms' and low dissolved oxygen concentrations in the lake.

Tenkiller Ferry Lake is a reservoir located in northeastern Oklahoma in Rogers County near the towns of Tenkiller Ferry, Nowata, and Claremore. The reservoir is at the downstream end of the Middle Verdigris River Basin (HUC8: 11070103) with a contributing drainage area of 4,339 square miles that includes contributing areas in both Kansas and Oklahoma (USACE, Tulsa District) (Figure 1). The Tenkiller Ferry Lake dam [-95.679 Longitude (W), 36.4225 Latitude (N)] is located on the Middle Verdigris River at river mile 90.2, about 2 miles southeast of Tenkiller Ferry in Rogers County, Oklahoma, and about 27 miles northeast of Tulsa in Tulsa County, Oklahoma.

Under authorization of the Flood Control Act of 1938, the reservoir was constructed by the US Army Corps of Engineers, Tulsa District. Construction began in 1950 and, after some project delays, the project was completed in 1974. The USACE continues to manage the lake. The purpose of the reservoir is flood control, water supply, navigation, recreation, and propagation of fish and wildlife. Normal pool surface area of the lake is 29,460 acres, the mean depth is 18.7 feet, and the storage volume is 457,160 acre-ft.

The City of Tulsa obtains approximately 40-50% of its water supply needs from Tenkiller Ferry Lake. The reservoir also serves as a raw water source for Public Service of Oklahoma, the City of Collinsville, Rural Water Districts of Rogers, Nowata, and Washington County, the City of Chelsea, and the City of Claremore (Oklahoma Department of Wildlife Conservation, Tenkiller Ferry Lake Management Plan, 2008). Raw water resource issues include taste and odor complaints and, beginning in 2003, the presence of zebra mussels throughout the lake and a dense accumulation of mussels in the water intake (US Army Corps of Engineers Tulsa District and City of Tulsa, 2012).

The Water Body ID (WBID) for Tenkiller Ferry Lake is OK121510010020-00 and water quality conditions in the lake are monitored by the Oklahoma Water Resources Board (OWRB) at 7 station locations as part of the Beneficial Use Monitoring Program (BUMP). The Oklahoma 303(d) List of Impaired Waters for 2012 identifies impairments of Tenkiller Ferry Lake because of dissolved oxygen (DO) and turbidity based on data collected by OWRB in 2012.

This report documents the data and assessment methods used to establish total maximum daily loads (TMDL) for Illinois River and Tenkiller Ferry Lake (OK121510010020-00). Data assessment and TMDL calculations are conducted in accordance with requirements of Section 303(d) of the federal Clean Water Act (CWA), Water Quality Planning and Management Regulations (40 CFR Part 130), United States Environmental Protection Agency (USEPA) guidance, and Oklahoma Department of Environmental Quality (DEQ) guidance and procedures. DEQ is required to submit all TMDLs to the USEPA for review and approval. Once the USEPA approves a TMDL, the waterbody may then be moved to Category 4 of a state's Integrated Water Quality Monitoring and Assessment Report, where it remains until compliance with water quality standards (WQS) is achieved (USEPA, 2003).

The purpose of this TMDL report is to establish waste load allocations (WLA) and load allocations (LA) determined to be necessary for maintaining sufficient dissolved oxygen levels in Tenkiller Ferry Lake to attain water quality targets to restore impaired Fish & Wildlife Propagation (FWP) beneficial uses. TMDLs determine the pollutant loading that a waterbody, such as Tenkiller Ferry Lake, can assimilate without exceeding water quality standards. TMDLs also establish the pollutant load allocation necessary to meet the water quality standards established for a waterbody based on the relationship between pollutant sources and water quality conditions in the waterbody. A TMDL consists of a waste load allocation (WLA) component, load allocation (LA) component, and a margin of safety (MOS). The WLA is the fraction of the total pollutant load apportioned to point sources, and includes municipal and industrial wastewater treatment facilities and urban storm water discharges regulated under the National Pollutant Discharge Elimination System (NPDES) as point sources. The LA is the fraction of the total pollutant load apportioned to nonpoint or distributed sources. The MOS is a percentage of the TMDL set aside to account for the lack of knowledge associated with natural processes in aquatic systems, assumptions of the watershed-lake model, and data limitations.

This report does not identify specific control actions (regulatory controls) or management measures (voluntary best management practices) necessary to reduce pollutant loading from the watershed. Watershed-specific control actions and management measures will be identified, selected, and implemented under a separate process involving stakeholders who live and work in the watershed, along with local, state, and federal government agencies.

ES1. Problem Identification and Water Quality Targets

Designation used of Illinois River, Barron Fork Ilinois River, and Flint Creek are aesthetics, agriculture, fist and wildlife propagation, fish consumption, primary body contact recreation, and public and priavete water supply. Designated uses of Tenkiller Ferry Lake are hydropower production, flood control, public and private water supply, agriculture, primary body contact recreation, and fish and wildlife propagation. As of the 2010 census, the Verdigris River basin population is estimated at 59,358 persons. Tenkiller Ferry Lake serves as a public water supply for several municipalities and rural towns located in the watershed. The lake is also an important recreational resource for the area with excellent fishing, swimming, camping, picnicking, boating, hunting, and sailing.

The 2012 Integrated Report and 303(d) list is used as the basis for identifying dissolved oxygen and turbidity as the water quality constituents responsible for impairments for FWP for a Warm Water Aquatic Community (WWAC) in Tenkiller Ferry Lake. Tenkiller Ferry Lake is designated as a Category 5a lake on the 2012 Oklahoma 303(d) list with a Priority 1 ranking. Category 5 defines a waterbody where, since water quality standards are not attained, the waterbody is impaired or threatened for one or more designated uses by pollutant(s), and the water body requires a TMDL. As shown in the 2012 Integrated Report, Tenkiller Ferry Lake is not supporting its designated uses for Fish & Wildlife Propagation for a Warm Water Aquatic Community because of dissolved oxygen and turbidity (OKWBID: OK121510010020-00). High levels of turbidity can have deleterious effects on raw water quality, such as taste and odor complaints and treatment costs of drinking water. Low levels of dissolved oxygen below the thermocline reflect decay of organic matter in the sediment bed and restricted transfer of dissolved oxygen from the surface layer because of summer thermal stratification.

The water quality targets established for Tenkiller Ferry Lake, based on statistics of the most recent 10 years of record used for the 2012 303(d) listing, are defined as 25 NTUs for turbidity. The recently revised Oklahoma water quality standards for dissolved oxygen for Tenkiller Ferry Lake are specified in relation to (a) spring and summer stratified conditions for the surface layer (epilimnion) and the anoxic volume of the lake within the hypolimnion and (b) non-stratified conditions for the surface layer (OWRB, 2014). Within the surface layer (epilimnion) during the early period of thermal stratification in spring, 10% or less of the dissolved oxygen samples shall be no less than 6 mg/L from April 1 to June 15. During the summer period of stratification from June 16-October 15, 10% or less of the dissolved oxygen samples shall be no less than 5 mg/L. During the remainder of the year (October 16 to March 31) 10% or less of the dissolved oxygen samples shall be no less than 5 mg/L for the months when the lake is non-stratified. DO criteria for a Warm Water Aquatic Community lake are also defined on the basis of the anoxic volume of the lake that is less than a target cutoff level of DO. During the period of thermal stratification, the lake is fully supporting if 50% or less of the lake volume is less than the target cutoff of 2 mg/L. Where water column DO data, rather than volumetric DO data, were used to determine impairment of the lake, the lake is considered to be fully supporting if 70% or less of the water column of sampling sites are less than the target cutoff of 2 mg/L.

ES2. Pollutant Source Assessment

Water quality constituents that relate to impairments of Tenkiller Ferry Lake include suspended sediment, chlorophyll-*a*, phosphorus, nitrogen, and total organic carbon (TOC). For Tenkiller Ferry Lake, there are no NPDES point sources directly discharging into the lake. Hence, there will be no waste load allocation for the wastewater point sources. As shown in Table ES- 1, the watershed runoff accounts for the largest existing share (94.5%) of nitrogen sources while benthic release from the lake bed (4.46%) contribute much smaller shares. For phosphorus loading, the watershed runoff (86.67%) accounts for over half of the existing loading while benthic release from the lake bed contributes 13.29% of the phosphorus inputs to the lake.

ES3. Watershed and Lake Model

A model framework was developed to establish the cause-effect linkage between pollutant loading from the watershed (the HSPF model) and water quality conditions in the lake (the EFDC model). Flow and pollutant loading from the watershed to the lake was simulated for 365-day simulation period period from January to December 2005 with the public domain HSPF watershed model. Watershed model results, other input and the results of the lake sediment flux model were used to estimate the relative contributions of point and nonpoint sources of pollutant loading presented in Table ES- 1.

Table ES- 1 Relative Contribution of Point and Nonpoint Source Loading of Pollutants into Tenkiller Ferry Lake (Model Validation, Jan-Dec 2005)

Source	Watershed	Atmospheric Deposition	Sediment Flux	Total
Total Nitrogen (TN)	109.8%	0.9%	-10.7%	100%
Total Phosphorus (TP)	81.2%	0.1%	18.7%	100%

Total Organic Carbon (TOC)	100.00%	0.00%	0.00%	100.0%

The EFDC model was developed to simulate water quality conditions in Tenkiller Ferry Lake for sediments, nutrients, organic matter, dissolved oxygen and chlorophyll-*a*. EFDC is a public domain surface water model that includes hydrodynamics, sediment transport, water quality, eutrophication and sediment diagenesis. The EFDC lake model was developed with water quality data collected at 4 station locations in the lake during the two-year period from January 2006 through December 2007. Model results were calibrated to 2006 observations for water level, water temperature, TSS, nitrogen, phosphorus, dissolved oxygen, organic carbon and algae biomass (chlorophyll-*a*). Model results were then validated, or confirmed, using water quality data collected in 2007. The Relative RMS Error performance targets are assigned as (a) 20% for water level and dissolved oxygen; (b) 50% for water temperature, nitrogen, phosphorus and total organic carbon; and (c) 100% for TSS and chlorophyll-*a*. Composite model performance statistics averaged over the 4 stations used for comparison to model results were attained for these constituents that were either better than, or close to, the target criteria.

The calibrated lake model was used to evaluate the water quality response to reductions in watershed nonpoint source loading of sediment, TOC and nutrients. Load reduction scenario model runs were performed to determine if water quality targets for turbidity and dissolved oxygen could be attained with point and nonpoint source load reductions based on 40% removal of loading for sediment and nutrients. Based on a long-term spin-up analysis of the watershed-lake model over an 8-year period, the model results indicated that compliance with water quality criteria for dissolved oxygen and turbidity could be achieved within a reasonable time frame. The calibrated and validated model results developed for Tenkiller Ferry Lake thus support the development of TMDLs for sediments, TOC, TN and TP to achieve compliance with water quality standards for turbidity and dissolved oxygen.

ES4. TMDL, Waste Load Allocation, Load Allocation and Margin of Safety

The linked watershed (HSPF) and lake (EFDC) model framework was used to calculate average annual Total Suspended Solids (TSS), TOC, Total Nitrogen and Total Phosphorus loads (kg/yr), that, if achieved, should meet the water quality targets established for turbidity and dissolved oxygen. For reporting purposes, the final TMDLs, according to EPA guidelines, are expressed as daily loads (kg/day).

Seasonal variation was accounted for in the TMDL determination for Tenkiller Ferry Lake in two ways: (1) water quality standards, and (2) the time period represented by the watershed and lake models. Oklahoma's water quality standards for dissolved oxygen for lakes are developed on a seasonal basis to be protective of fish and wildlife propagation for a warm water aquatic community at all life stages, including spawning. Within the surface layer, dissolved oxygen standards specify that DO levels shall be no less than 6 mg/L from April 1 to June 15 to be protective of early life stages and no less than 5 mg/L for the remainder of the year during summer stratified conditions (June 16 to October 15) and winter well-mixed conditions (October 16 through March 31). Under summer stratified conditions in Tenkiller Ferry Lake, the hypoxic volume of the lake, defined by a DO target of 2 mg/L, is not to be greater than 50% of the lake volume. Where water column DO data, rather than volumetric DO data, were used to determine impairment of the lake, the lake is considered to be fully supporting if 70% or less of the water column of sampling sites are less than the target cutoff of 2 mg/L. Seasonality was also accounted for in the TMDL analysis by developing the models using two years of streamflow and water quality data collected as part of routine water quality monitoring programs conducted by OWRB and the USACE. The watershed and lake models were developed with hourly to sub-hourly time steps over two years of simulation (2006-2007) with meteorological data representative of the dry and wet hydrologic conditions in the watershed that characterized much of eastern Oklahoma during 2006-2007.

EPA guidance about the Margin of Safety (MOS) for development of TMDLs states that: A margin of safety expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL; e.g., derivation of numeric targets, modeling assumptions, or effectiveness of proposed management actions which ensures attainment and maintenance of water quality standards for the allocated pollutant [40 CFR 130.33(b)(7)].

EPA guidance identifies two approaches for defining the MOS. In the first approach, an explicit MOS quantifies an allocation amount separate from other load and wasteload allocations. In the second approach, an implicit MOS is not specifically quantified but consists of conservative assumptions used in the TMDL analysis. http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/TMDL-ch3.cfm

The TMDL determined for Tenkiller Ferry Lake applies an implicit Margin of Safety (MOS) based on a conservative assumption for derivation of more stringent numeric water quality targets for turbidity, and dissolved oxygen. Adoption of a 10% MOS as a conservative assumption for the derivation of more stringent water quality targets for turbidity and the anoxic percentage of the water column will ensure an adequate implicit MOS for the determination of load allocations (LA) for Tenkiller Ferry Lake. Turbidity, a measure of water clarity, is caused by scattering and adsorption of light by suspended particles in the water column. Turbidity, however, cannot be expressed as a mass load. Total suspended solids (TSS) are therefore modeled and evaluated as a surrogate water quality constituent for turbidity using a site-specific relationship derived from paired TSS and turbidity measurements in Tenkiller Ferry Lake. The TMDL for TSS, TOC, TN and TP, determined from the lake model response to watershed load reductions, is based on 40% reduction of the existing watershed runoff loads estimated with the HSPF model (Table ES-2).

The statistical methodology, documented in EPA (2007) "Options for Expressing Daily Loads in TMDLs", for computing the maximum daily load (MDL) limit is based on a long-term average load (LTA), temporal variability of the pollutant loading dataset expressed by the coefficient of variation (CV), the Z-score statistic (1.645) for 95% probability of occurrence and the assumption that flow and pollutant loading from the watershed can be described as a lognormal distribution (). The load allocation (LA) is computed from the MDL and the percentage split of the total existing PS and NPS load accounted for by NPS watershed runoff (Table ES-3). As there are no direct point source discharges of wastewater into Tenkiller Ferry Lake, the percentage split for the PS load is zero and the percentage split for the NPS load is 100%.

Table ES-2 Existing Long Term Loading, Load Reduction Rate and Reduced Long Term Loading for Tenkiller Ferry Lake

Water Quality Constituent	LTA, Existing Annual (kg/yr)	Load Reduction (%)	LTA, Reduced Annual (kg/yr)	LTA, Reduced Daily (kg/day)

Total Nitrogen (TN)	2,231,802	72%	624,905	1,712
Total Phosphorus (TP)	102,896	72%	28,811	79
Total Organic Carbon (TOC)	2,101,332	72%	588,373	1,612

Table ES-3 TMDL for Tenkiller Ferry Lake: LA for Watershed

Water Quality Constituent	**LTA, Reduced Daily (kg/day)**	**Load** CV **(n=363)**	**Z-Score** for **95%** Probability	**MDL** (TMDL) **Load** kg/day
Total Nitrogen (TN)	1,712	1.569	1.645	5,754
Total Phosphorus (TP)	79	0.993	1.645	219
Total Organic Carbon (TOC)	1,612	1.432	1.645	5,243
LTA- Long Term Average Load; CV- Coefficient of Variation				

* Implicit Margin of Safety (MOS) based on conservative assumptions for derivation of more stringent numeric water quality targets for turbidity and dissolved oxygen.

The phosphorous TMDL for the upstream reaches were developed based on HSPF model. The model was calibrated to the historical conditions using the monitoring data. The calibrated model was them used to find the reduction scenario that meets the water quality target. The MOS was implicitly incorporated into this TMDL. Based on the load-allocation scenario analyses, the TMDL allocation plans that will meet 30-day running geometric mean of 0.037 mg/l are presented in Table ES-4 and table ES-5.

Table ES-4 TMDL for Selected Reaches within the IRW

TMDL Reach (Segment)	**TMDL**	**WLA**	**LA**	**FG**	**MOS**
RCHRES 512 - Flint Creek (OK121700060080_00)	9.2	0.5	8.8	0.01	Implicit
RCHRES 523 - Flint Creek (OK121700060010_00)	27.6	0.6	26.9	0.03	Implicit
RCHRES 524 - Flint Creek (OK121700030290_00)	27.9	0.6	27.3	0.03	Implicit
RCHRES 630 - Illinois River (Stateline)	291.3	18.8	272.2	0.29	Implicit
RCHRES 650 - Illinois River (OK121700030350_00)	317.9	18.7	298.9	0.32	Implicit
RCHRES 752 - Baron Fork (OK121700050010_00)	180.9	0.6	180.2	0.18	Implicit
RCHRES 800 - Illinois River (OK121700030280_00)	351.6	19.3	332.0	0.35	Implicit
RCHRES 870 - Illinois River (OK121700030080_00)	359.4	19.3	339.8	0.36	Implicit
RCHRES 890 - Illinois River (OK121700030010_00)	363.6	19.8	343.4	0.36	Implicit

Table ES-5 Daily Expressions of TMDLs for Selected Reaches within the IRW

TMDL Reach (Segment)	**TMDL**	**WLA**	**LA**	**FG**	**MOS**

RCHRES 512 - Flint Creek (OK121700060080_00)	30.7	1.6	29.1	0.03	Implicit
RCHRES 523 - Flint Creek (OK121700060010_00)	95.8	2.3	93.4	0.10	Implicit
RCHRES 524 - Flint Creek (OK121700030290_00)	97.4	2.3	95.0	0.10	Implicit
RCHRES 630 - Illinois River (Stateline)	1059.0	68.3	989.6	1.06	Implicit
RCHRES 650 - Illinois River (OK121700030350_00)	1157.6	68.2	1088.3	1.16	Implicit
RCHRES 752 - Baron Fork (OK121700050010_00)	656.4	2.1	653.6	0.66	Implicit
RCHRES 800 - Illinois River (OK121700030280_00)	1292.1	70.9	1219.8	1.29	Implicit
RCHRES 870 - Illinois River (OK121700030080_00)	1344.7	72.0	1271.3	1.34	Implicit
RCHRES 890 - Illinois River (OK121700030010_00)	1366.9	74.6	1291.0	1.37	Implicit

ES5. Public Participation

This draft report is submitted to EPA for technical review. After the technical approval, a public notice will be circulated to the local newspapers and/or other publications in the area affected by the TMDLs in the Tenkiller Ferry Lake study area. The public will have opportunities to review the TMDL report and make written comments during a public comment period that lasts 45 days. Depending on the interest and responses from the public, a public meeting may be held within the watershed affected by the TMDLs in this report. If a public meeting is held, the public will also have opportunities to ask questions and make formal oral comments at the meeting and/or to submit written comments at the public meeting.

All written comments received during the public notice period become a part of the record of these TMDLs. All comments will be considered and the TMDL report will be revised according to the comments, if necessary, prior to the ultimate completion of these TMDLs for submission to EPA for final approval.

On <INSERT DATE> there was an informational meeting for the public to discuss the TMDL process for Illinois River Watershed and Tenkiller Ferry Lake. On <INSERT DATE>, EPA preliminarily approved the draft TMDL report and gave permission to go forward with the Public Comment period. The public comment period was open from <INSERT DATE> to <INSERT DATE>. A Public Meeting was held the evening of <INSERT DATE>. By the time the public comment period ended, DEQ had received <# of Comments> comments from <# of entities> entities. The comments and responses can be found in Appendix G.

SECTION 1. INTRODUCTION

1.1. Clean Water Act and TMDL Program

Section 303(d) of the federal Clean Water Act (CWA) and U.S. Environmental Protection Agency (USEPA) Water Quality Planning and Management Regulations (40 Code of Federal Regulations [CFR] Part 130) require states to develop total maximum daily loads (TMDL) for waterbodies not meeting designated uses where technology-based controls are in place. TMDLs establish the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream water quality conditions, so States can implement water quality-based controls to reduce pollution from point and nonpoint sources and restore and maintain water quality (USEPA, 1991a).

Several segments of the Illinois River are on the State of Oklahoma's 303(d) list for Total Phosphorus (TP), while the mainstem Illinois River in Arkansas is not listed for TP. However, several tributaries to the Illinois River in Arkansas (e.g. Osage Creek, Muddy Fork, and Spring Creek) have been previously designated as Phosphorus-impaired and were included in the State's 2008 Clean Water Act 303(d) list.

Tenkiller Ferry Lake is identified on Oklahoma's 2016 303(d) list as impaired due to elevated nutrients, and is a high-priority target for TMDL development (ODEQ, 2016). Tenkiller Ferry Lake is also listed as a Nutrient Limited Water (NLW) indicating that the aesthetics beneficial use is considered threatened by nutrients (OWRB, 2013). Water quality impairments in the lake are for dissolved oxygen (DO), chlorophyll-*a*, and trophic state index (TSI). Analysis of the water quality data collected by OWRB indicates that eutrophication of the lake occurs during summer periods, which is primarily attributed to excess phosphorus inputs from both point and nonpoint sources, especially from the untreated poultry litter on watershed pasture (Cooke et al., 2011).

This report documents the data and assessment used to establish TMDLs for dissolved oxygen, and chlorophyll-*a* for Tenkiller Ferry Lake reservoir in Cherokee and Sequoyah Counties in eastern Oklahoma at the downstream of the Illinois River Basin. High levels of chlorophyll-*a* and and an elevated TSI reflect elevated nutrient loading from the watershed and subsequent low levels of dissolved oxygen, particularly at depths deeper than the seasonal thermocline which in turn reflect the effects of decomposition of organic matter below the thermocline and within the sediment bed and restricted mixing of dissolved oxygen from the surface layer of the lake to the lower layer of the lake during conditions of summer stratification.

The purpose of this TMDL report is to establish organic matter and nutrient load allocations necessary for improving dissolved oxygen, chlorophyll-*a* and TSI levels in the lake as the first step toward restoring water quality in this lake. TMDLs determine the pollutant loading a waterbody can assimilate without exceeding applicable water quality standards (WQS). TMDLs also establish the allocation of pollutant loads necessary to meet the WQS established for a waterbody based on the cause-effect relationship between pollutant sources and water quality conditions in the waterbody. A TMDL consists of three components: (1) wasteload allocation(s) (WLA(s)), (2) load allocation(s) (LA(s)), and (3) a margin of safety (MOS). The WLA is the fraction of the total pollutant load apportioned to point sources. Point sources include municipal and industrial wastewater facilities and urban storm water discharges regulated under the CWA NPDES. The LA is the fraction of the total pollutant load apportioned to nonpoint sources (NPS). The MOS is a portion of the TMDL loading set aside to account for the lack of knowledge associated with natural process in aquatic systems, surface water model assumptions, and data limitations.

Data assessment and TMDL calculations are conducted in accordance with requirements of Section 303(d) of the CWA, Water Quality Planning and Management Regulations (40 CFR Part 130), USEPA guidance, and Oklahoma Department of Environmental Quality (DEQ) guidance and procedures. Once the USEPA approves a TMDL, then the waterbody may be moved to Category 4a of a State's Integrated Water Quality Monitoring and Assessment Report, where it remains until compliance with water quality standards (WQS) is achieved (USEPA, 2003).

This report does not stipulate specific control actions (regulatory controls) or management measures (voluntary best management practices) necessary to reduce nutrients within the lake watershed. Watershed-specific control actions and management measures will be identified, selected, and implemented under a separate process involving stakeholders who live and work in the watersheds, along with local, state, and federal government agencies.

Tenkiller Ferry Lake is on Oklahoma's 2016 303(d) list for impaired beneficial uses of Fish and Wildlife Propagation for Warm Water Aquatic Community life and Public and Private Water Supply. Causes of impairment have been identified as low dissolved oxygen, high chlorophyll-*a* and high TSI (OKWBID OK121700020020-00 and OKWBID OK121700020220-00) (ODEQ, 2016).

Figure 1.1 shows a location map of Tenkiller Ferry Lake and the contributing sub-watersheds of the drainage basin to the lake. The map displays the locations of stream water quality monitoring (WQM) stations in the watershed, and lake water quality monitoring stations used for this TMDL determination. Water quality data obtained from the lake stations over the past 10 years were used as the basis for placement of Tenkiller Ferry Lake on the Oklahoma 303(d) list.

1.2. Illinois River Watershed and Tenkiller Ferry Lake Description

The Illinois River begins in the Ozark Mountains in the northwest corner of Arkansas, and flows for 50 miles west into northeastern Oklahoma (Figure 1.1). The Arkansas portion of the Illinois River Watershed is characterized by rapidly developing urban areas and intensive agricultural animal production. It includes Benton, Washington and Crawford Counties and according to the US Census Bureau, the population of Benton and Washington Counties increased by 45% between 1990 and 2000. This growth rate continued through 2010 with Benton County growing at 44% and Washington County at 29%. Arkansas ranked second in the nation in broiler production in 1998. Benton and Washington Counties ranked first and second respectively in the state. Other livestock production such as turkey, cattle and hogs are also all significant in this area. Upon entering Oklahoma, the river flows southwest and then south through the mountains of eastern Oklahoma for 65 miles, until it enters the Tenkiller Ferry Lake reservoir, also known as Lake Tenkiller. The upper section of the Illinois River in Oklahoma is a designated scenic river and home to many native species of bass with spring runs of white bass. The lower section, below Tenkiller dam flows for 10 miles to the Arkansas River, and is a designated year-round trout stream, stocked with rainbow and brown trout.

Tenkiller Ferry Lake is located in the Illinois River watershed (Hydrologic Unit Code 11110103), which crosses the Oklahoma-Arkansas boundary and covers 1,053,032 acres. The Illinois River flows west-southwest from Arkansas and into Oklahoma, where it drains into Tenkiller Ferry Lake before flowing into the Arkansas River. Tenkiller Ferry Lake is located in the southwestern portion of the basin with an area of 12,900 acres (OWRB, 2013). The main tributaries to the lake include the Illinois River, Baron Fork, Tahlequah Creek, Flint Creek, and Caney Creek. Figure 1 shows the location of the Illinois River watershed, the Tenkiller Ferry Lake drainage basin, Tenkiller Ferry Lake, and its main tributaries.

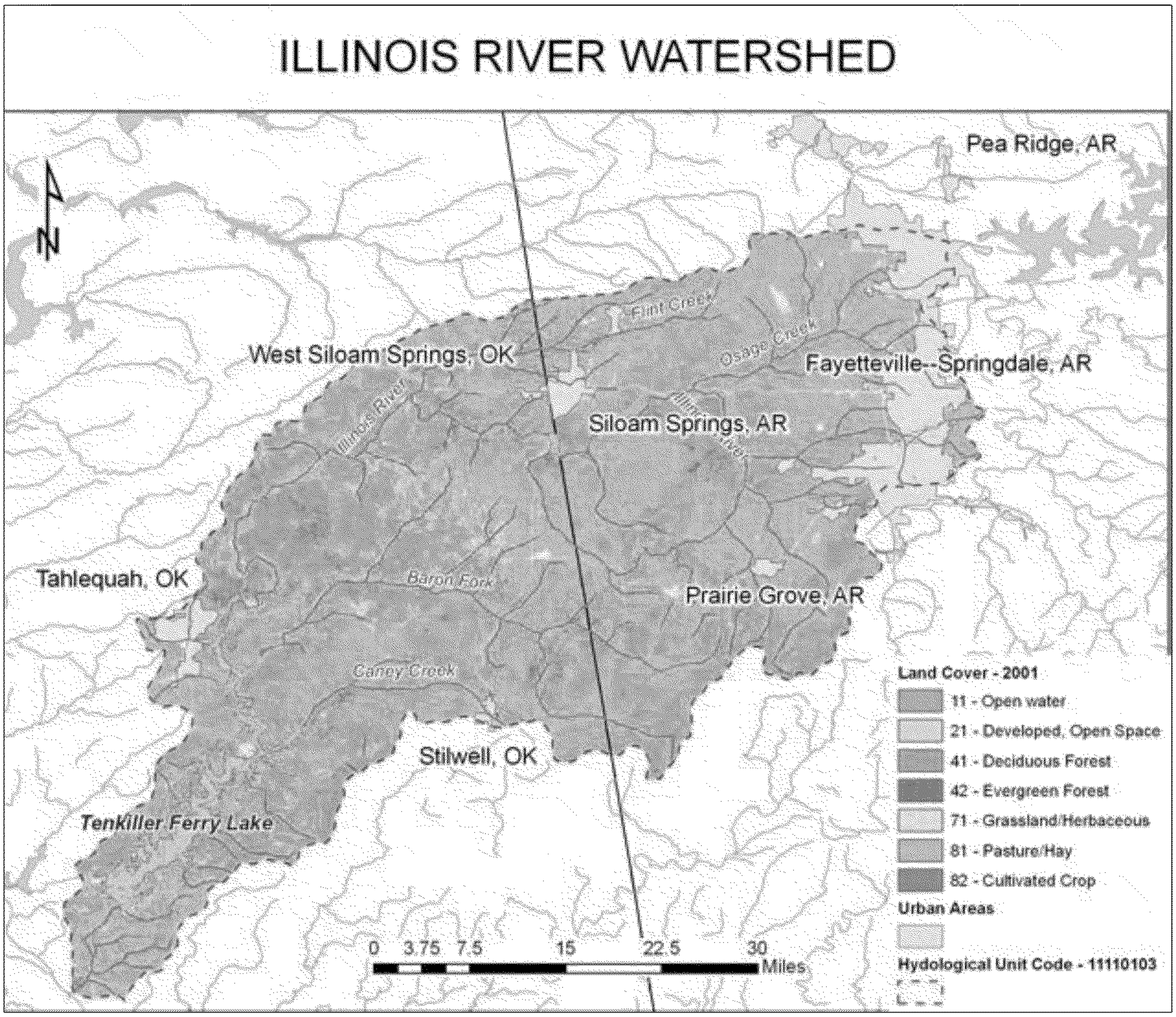


Figure 1.1 Location of Tenkiller Ferry Lake and Contributing Watershed

Under authorization of the Flood Control Act of 1938, the reservoir was constructed by the US Army Corps of Engineers, Tulsa District. Construction began in 1947 and was completed in 1953 and under authorization of the River and Harbor Act of 1946, power was placed on the line in 1953. The USACE continues to manage the lake. Normal pool elevation is 632 feet and the surface area of the lake is 12,900 acres, the mean depth is feet, and the storage volume is 668,191 acre-ft (Table 1.1).

Table 1.1 Physical Characteristics of Tenkiller Ferry Lake

Property Name	Unit	Value
Drainage Area	Square miles	1,610
Surface Area @ Normal Pool Elevation*	acres	12,900
Normal Conservation Pool Elevation	ft, NGVD29	632
Conservation Pool Storage Volume	acre-ft	668,191
Flood Pool Elevation	ft, NGVD29	667
Flood Control Pool Storage Volume	acre-ft	1,238,583
Average Depth	ft	51
Maximum Depth	ft	165
Shoreline	miles	130
* Elevation: vertical datum -NGVD29		
Data Sources:		
USACE- http://www.swt-wc.usace.army.mil/TENK.lakepage.html		

Designated uses of Tenkiller Ferry Lake include flood control, public and private water supply, navigation, recreation, and fish and wildlife propagation. As of the 2010 census, the Illinois River basin population is estimated at 59,358. Tenkiller Ferry Lake serves as a public water supply source for the City of Tulsa, Public Service of Oklahoma, the City of Collinsville, Rural Water Districts of Rogers, Nowata, and Washington County, the City of Chelsea, and the City of Claremore (Oklahoma Department of Wildlife Conservation, Tenkiller Ferry Lake Management Plan, 2008).

The total Verdigris River basin is about 2,737,822 acres as shown in Figure 1.1. The portion of the Verdigris River basin that is included in the HSPF watershed model is presented in Figure 1-2 with the exclusion of the contributing areas of 1,246,672 acres attributed to the four federal reservoirs: Toronto Lake, Fall River Lake, Elk City Lake, and Big Hill Lake. The time series data of flows and water quality constituent loads from these four federal reservoirs serve as the boundary conditions of the watershed model. As shown in both Figure 1 1 and Figure 1 2, most of the watershed contributing area is located in the state of Kansas with 492,804 acres of the contributing area in Oklahoma.

The watershed is generally characterized as being in the Osage Cuestas Ecoregion with a physiography of cuestas and gentle undulating plains dissected by perennial and intermittent streams (Woods et al., 2005). Silty and clayey residuum and colluvium with alternating layers of Pennsylvanian sandstone, limestone, and shale characterize area geology. Glacial drift is fairly abundant in the extreme northern part of this ecoregion. Soils in the western part of the basin were developed from the underlying limestones and shales and in most parts of the watershed the soils are relatively shallow, making them best suited for native pastures. In the eastern part of the basin, soils are generally sandy residual soils which are low in fertility and quite erosive.

These soils occur on undulating to hilly topography and are relatively shallow. In general, this area is more suitable for grazing than for cultivation.

Table 1 2 summarizes the percentages and acres of land use categories for the contributing watershed of the Verdigris River basin used for the watershed model. Land use and land cover data were derived from the 2006 National Land Cover Database (NLCD) database. The most common land use category in the study area is Pasture with 45.4% of the watershed area. In addition to Cropland land use (11.5%) and Forest land use (13.5%), about quarter of the basin is classified as Grassland with 23.3% of the watershed area. Urban developed land use categories account for only 5.7% of the watershed area and Wetland accounts for 0.5%. Land use distribution within the watershed is shown in Figure 1 3.

SECTION 2. PROBLEM IDENTIFICATION AND WATER QUALITY TARGETS

2.1. Water Quality Standards/Criteria

This subsection describes the relevant water quality standards and criteria for the states of Arkansas and Oklahoma.

2.1.1 Arkansas Water Quality Standards/Criteria

Water quality standards for Arkansas waterbodies are listed by ecoregion in Regulation No. 2 (Arkansas Pollution Control and Ecology Commission [APCEC] 2007a).

2.1.1.1 ***Arkansas Nutrient Criteria***

For nutrients, the Arkansas water quality standards have a narrative criterion. The narrative criteria for nutrients in Arkansas are as follows:

Materials stimulating algal growth shall not be present in concentrations sufficient to cause objectionable algal densities or other nuisance aquatic vegetation or otherwise impair any designated use of the waterbody. Impairment of a waterbody from excess nutrients is dependent 5-8 on the natural waterbody characteristics such as stream flow, residence time, stream slope, substrate type, canopy, riparian vegetation, primary use of waterbody, season of the year and ecoregion water chemistry. Because nutrient water column concentrations do not always correlate directly with stream impairments, impairments will be assessed by a combination of factors such as water clarity, periphyton or phytoplankton production, dissolved oxygen values, dissolved oxygen saturation, diurnal dissolved oxygen fluctuations, pH values, aquatic-life community structure and possibly others. However, when excess nutrients result in an impairment, based upon Department assessment methodology, by any Arkansas established numeric water quality standard, the waterbody will be determined to be impaired by nutrients.

2.1.2 Oklahoma Water Quality Standards/Criteria

Chapters 45 and 46 of Title 785 of the Oklahoma Administrative Code (OAC) contain Oklahoma's WQS and implementation procedures, respectively. The Oklahoma Water Resources Board (OWRB) has statutory authority and responsibility concerning establishment of state water quality standards, as provided under 82 Oklahoma Statute [O.S.], §1085.30. This statute authorizes the OWRB to promulgate rules …*which establish classifications of uses of waters of the state, criteria to maintain and protect such classifications, and other standards or policies pertaining to the quality of such waters*. [O.S. 82:1085:30(A)]. Beneficial uses are designated for all waters of the state. Such uses are protected through restrictions imposed by the anti-degradation policy statement, narrative water quality criteria, and numerical criteria (OWRB, 2016). An excerpt of the Oklahoma WQS (Chapter 45, Title 785) summarizing the State of Oklahoma Anti-degradation Policy is provided in Appendix C. Table 2.1, excerpted from the 2016 Integrated Report, lists beneficial uses designated for Tenkiller Ferry Lake (ODEQ, 2016). Beneficial uses include:

- AES – Aesthetics

- AG – Agriculture
- WWAC – Warm Water Aquatic Community, Fish and Wildlife Propagation
- FISH – Fish Consumption
- PBCR – Primary Body Contact Recreation
- PPWS – Public & Private Water Supply

Table 2.1 2016 Integrated Report – Oklahoma §303(d) List of Impaired Waters (Category 5a) for Tenkiller Ferry Lake

Waterbody Name	Waterbody ID	AES	AG	WWAC	FISH	PBCR	PPWS
Tenkiller Ferry Lake	OK121700020020_00	N	F	N	I	F	I
Tenkiller Ferry Lake, Illinois River Arm	OK121700020220_00	N	F	I	I	F	N
Illinois River	OK121700030010_00	N	F		F	N	F
Illinois River	OK121700030080_00	N	I		F	N	I
Illinois River	OK121700030280_00	N	F		F	N	F
Illinois River	OK121700030350_00	N	F		F	N	F
Illinois River, Baron Fork	OK121700050010_00	N	F		F	N	F
Flint Creek	OK121700030290_00	N	F		X	I	X
Flint Creek	OK121700060010_00	N	F		F	N	F

F – Fully supporting; N – Not supporting; I – Insufficient information; X – Not assessed
Source: 2016 Integrated Report, DEQ 2016

The 2016 Integrated Report and 303(d) list is used as the basis for identifying dissolved oxygen as the water quality constituent responsible for impairments for Fish & Wildlife Propagation (FWP) for a Warm Water Aquatic Community (WWAC) and identifying chlorophyll-*a* and total phosphorus (TP) as the water quality constituents responsible for impairments for Aesthetics (AES) and Public & Private Water Supply (PPWS) in Tenkiller Ferry Lake and Illinois River Arm of the lake. **Table 2.2** summarizes the impairment status from the 2016 Integrated Report for the Waterbody IDs of Tenkiller Ferry Lake. Tenkiller Ferry Lake is designated as a Category 5a lake. Category 5 defines a waterbody where, since the water quality standard is not attained, the waterbody is impaired or threatened for one or more designated uses by a pollutant(s), and the water body requires a TMDL. This category constitutes the Section 303(d) list of waters impaired or threatened by a pollutant(s) for which one or more TMDL(s) are needed. Sub-Category 5a means that a TMDL is underway or will be scheduled. The TMDLs established in this report, which are a necessary step in the process of restoring water quality, address water quality issues related to nonattainment of the public and private water supply, aesthetics and warm water aquatic community beneficial uses.

Table 2.2 2016 Integrated Report – Oklahoma 303(d) List for Tenkiller Ferry Lake and Illinois River

Waterbody Name	Waterbody ID	Type[1]	Size[2]	TMDL Date	Priority	DO	Chl-a	TP
Tenkiller Ferry Lake	OK121700020020_00	L	8,442	2012	1	●		●
Tenkiller Ferry Lake, Illinois River Arm	OK121700020220_00	L	5,032	2012	1		●	●
Illinois River	OK121700030010_00	R	7.68					●
Illinois River	OK121700030080_00	R	31.68					●
Illinois River	OK121700030280_00	R	15.65					●
Illinois River	OK121700030350_00	R	5.18					●
Illinois River, Baron Fork	OK121700050010_00	R	25.15					●
Flint Creek	OK121700030290_00	R	1.60					●
Flint Creek	OK121700060010_00	R	7.75					●

[1]L- lake and R- River or stream; [2] Size is miles for river or stream and acres for lake

2.1.2.1 *Nutrient Standards for Scenic Rivers*

The following excerpt from the Oklahoma WQS [OAC 785:45-5-19(c)(2)] stipulates the nutrient numerical criterion for waters designated Scenic Rivers to maintain and protect "Aesthetics" beneficial uses (OWRB, 2011):

> *The thirty (30) day geometric mean total phosphorus concentration in waters designated "Scenic River" in Appendix A of this Chapter shall not exceed 0.037 mg/L. The criterion stated in this subparagraph applies in addition to, and shall be construed so as to be consistent with, any other provision of this Chapter which may be applicable to such waters. Such criterion became effective July 1, 2002 and shall be implemented as authorized by state law through Water Quality Standards Implementation Plans and other rules, permits, settlement agreements, consent orders, compliance orders, compliance schedules or voluntary measures designed to achieve full compliance with the criterion in the stream by June 30, 2012.*

2.1.2.2 *Chrolophyll-a Standards for SWS Lakes*

The following excerpt from the Oklahoma WQS [OAC 785:45-5-10(7)] stipulates the chlorophyll-*a* numerical criterion to maintain and protect "Public and Private Water Supply" beneficial uses (OWRB, 2016).

The long-term average concentration of chlorophyll-a at a depth of 0.5 meters below the surface shall not exceed 0.010 milligrams per liter in Wister Lake, Tenkiller Ferry Reservoir, nor any waterbody designated Sensitive Public and Private Water Supply (SWS). Wherever such criterion is exceeded, numerical phosphorus or nitrogen criteria or both may be promulgated.

2.1.2.3 Dissolved Oxygen Standards for Lakes

Oklahoma water quality standards for dissolved oxygen are found in the Oklahoma Administrative Code (OAC), Title 785, Chapter 45 (OAC785:45) (2016). Compliance with the standards for dissolved oxygen is specified in relation to the surface layer of a waterbody for early life stages between April 1 and June 15 and other life stages in summer conditions between June 16 and October 15 and winter conditions between October 16 and March 31 and whole lake water column.

Table 2.3 summarizes the water quality standards for dissolved oxygen within the surface layer of a waterbody.

Table 2.3 Dissolved Oxygen Criteria to Protect Fish and Wildlife Propagation and All Subcategories Thereof. Source: OWRB (2016)

Dissolved Oxygen Criteria to Protect Fish and Wildlife Propagation and All Subcategories Thereof [1]

SUBCATEGORY OF FISH AND WILDLIFE PROPAGATION (FISHERY CLASS)	DATES APPLICABLE	DO CRITERIA[4] (MINIMUM) (mg/L)	SEASONAL TEMPERATURE (°C)
Habitat Limited Aquatic Community			
Early Life Stages	4/1 - 6/15	4.0	25[3]
Other Life Stages			
Summer Conditions	6/16 - 10/15	3.0	32
Winter Conditions	10/16 - 3/31	3.0	18
Warm Water Aquatic Community[5]			
Early Life Stages	4/1 - 6/15	6.0[2]	25[3]
Other Life Stages			
Summer Conditions	6/16 - 10/15	5.0[2]	32
Winter Conditions	10/16 - 3/31	5.0	18
Cool Water Aquatic Community & Trout			
Early Life Stages	3/1 - 5/31	7.0[2]	22
Other Life Stages			
Summer Conditions	6/1 - 10/15	6.0[2]	29
Winter Conditions	10/16 - 2/28	6.0	18

1 For use in calculation of the allowable load.
2 Because of natural diurnal dissolved oxygen fluctuation, a 1.0 mg/l dissolved oxygen concentration deficit shall be allowed for not more than eight (8) hours during any twenty-four (24) hour period.
3 Discharge limits necessary to meet summer conditions will apply from June 1 of each year. However, where discharge limits based on Early Life Stage (spring) conditions are more restrictive, those limits may be extended to July 1.
4 DO shall not exhibit concentrations less than the criteria magnitudes expressed above in greater than 10% of the samples as assessed across all life stages and seasons.
5 For Lakes, the warm water aquatic community dissolved oxygen criteria expressed above are applicable to the surface waters.

In addition to water quality standards for dissolved oxygen within the surface layer, the Oklahoma water quality standards for dissolved oxygen also specify criteria based on the percent volume of the lake or percent of the water column (OAC785:45, 2016).

For lakes, no more than 50% of the water volume shall exhibit a DO concentration less than 2.0 mg/L. If no volumetric data is available, then no more than 70% of the water column at any given sample site shall exhibit a DO concentration less than 2.0 mg/L. If a lake specific study including historical analysis demonstrates that a different percent volume or percent water column than described above is protective of the WWAC use, then that lake specific result takes precedence.

2.1.1.4 Aesthetics -Total Phosphorus Standards for Lakes

For lakes, no numerical standard is set for total phosphorus for the aesthetics beneficial use. However, *the aesthetics beneficial use for lakes and nonwadable streams is considered attained with respect to nutrients if planktonic chlorophyll-a values in the water column indicate a Carlson's TSI of less than 62 which is determined by the formula TSI=9.81*Ln(Chlorophyll-a)+30.6.* A chlorophyll-*a* concentration of 24.5 ug/L is equivalent to a Carlson's TSI of 62.

2.2. Overview of Water Quality Problems and Issues

Based on an assessment of water quality monitoring data for the 2016 Integrated Report, Oklahoma DEQ has determined that Tenkiller Ferry Lake is not supporting its designated uses for Fish and Wildlife Propagation for a Warm Water Aquatic Community because of low dissolved oxygen and Tenkiller Ferry Lake, Illinois River Arm is not supporting its designated uses for Public and Private Water Supply because of high level of chlorophyll-*a*. The whole lake including Illinois River Arm is not supporting its Aesthetics beneficial use because of high level nutrients (TP). Within the 1,645-square mile drainage basin, external sources of nutrient related to low dissolved oxygen, high chlorophyll-*a* and high TP problems in Tenkiller Ferry Lake include loading from the Illinois River basin, Baron Fork basin and Caney Creek basin. In addition to these major inflows, nutrient loading to Tenkiller Ferry Lake is also contributed by local land use driven loading from several small tributaries and direct overland runoff. A TMDL assessment for Tenkiller Ferry Lake is required by the CWA to determine appropriate load reductions for these external sources that could be implemented to achieve compliance with water quality standards for the lake.

Table 2.4 summarizes the site designation names, station numbers and geographic locations of the water quality monitoring stations maintained by OWRB in Tenkiller Ferry Lake.

Figure 2.1 shows the locations of the OWRB stations in the lake and the Illinois River Arm.

Table 2.4 OWRB and USACE Water Quality Monitoring Stations for Tenkiller Ferry Lake (WBID - OK121700020020_00 and OK121700020220_00)

Station_ID	Agency	Longitude (W)	Latitude (N)
Site1	OWRB	35.600017	-95.044628
Site2	OWRB	35.674433	-94.976408
Site3	OWRB	35.739050	-94.954261
Site4	OWRB	35.755422	-94.905072
Site5	OWRB	35.763844	-94.892400

Site6	OWRB	35.766339	-94.887192
Site7	OWRB	35.639381	-95.014631

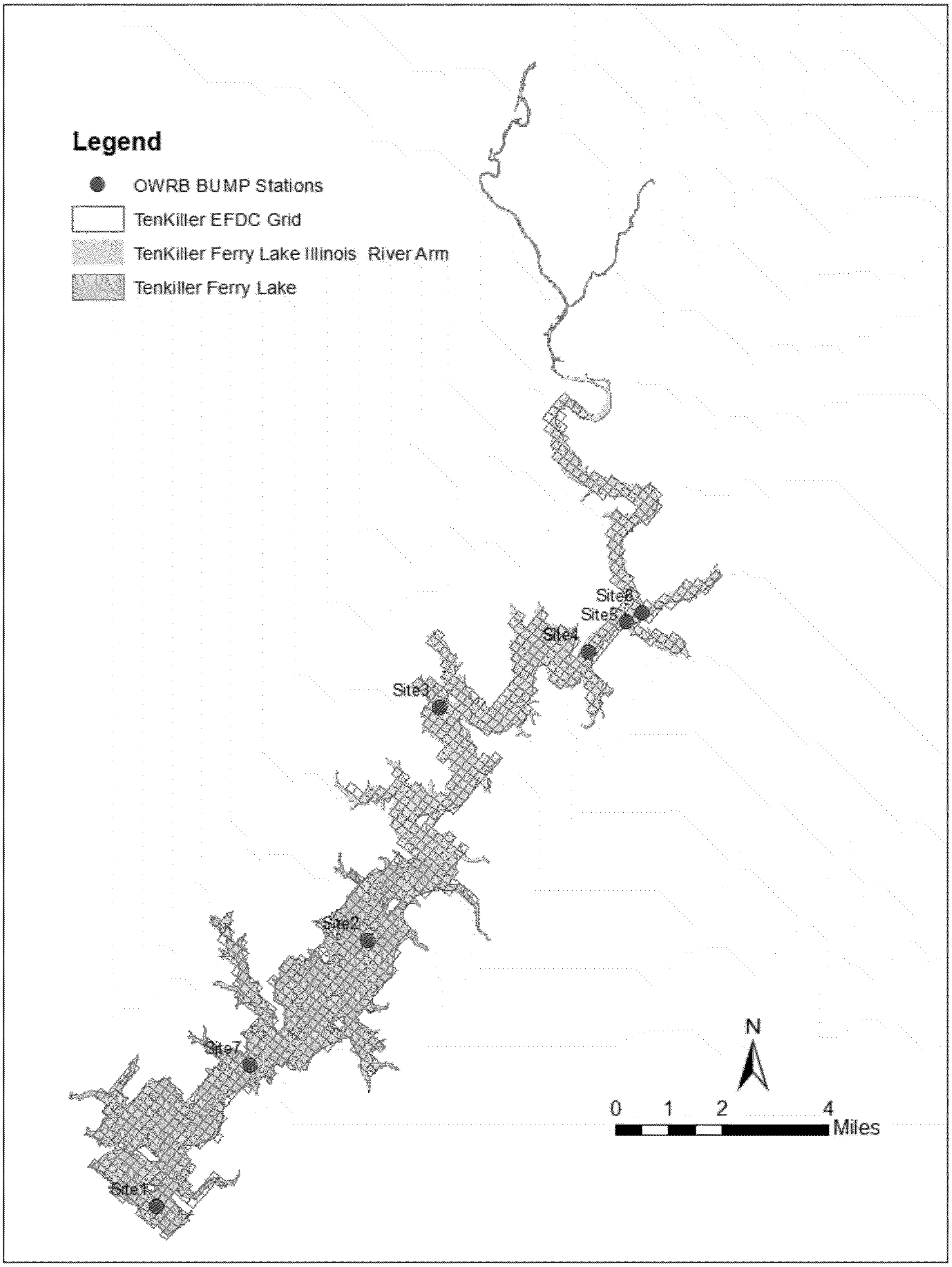


Figure 2.1 OWRB BUMP Water Quality Monitoring Stations for Tenkiller Ferry Lake

2.3. Water Quality Observations and Targets for Total Phosphorus, Dissolved Oxygen, and Chlorophyll-*a*

Water quality targets adopted for the Tenkiller Ferry Lake TMDL study for dissolved oxygen, chlorophyll-*a* and total phosphorus are as follows:

- Dissolved Oxygen for early life stages from April 1 to June 15: Within the surface/epilimnion layer for protection of fish and wildlife propagation in warm water aquatic community DO no less than 6 mg/L.
- Dissolved Oxygen for other life stages in summer conditions June 16 to October 15: Within the surface/epilimnion layer for protection of fish and wildlife propagation in warm water aquatic community DO no less than 5 mg/L.
- Dissolved Oxygen for other life stages in winter conditions October 16 to March 31: Within the surface/epilimnion layer for protection of fish and wildlife propagation in warm water aquatic community DO no less than 5 mg/L.
- Dissolved Oxygen: Anoxic volume of the lake, defined by a DO target level of 2 mg/L, shall not exceed 50% of the lake volume based on volumetric data or 70% of the water column at any given sample site.
- Chlorophyll-*a*: average concentration of chlorophyll-*a* at a depth 0.5 meters below the surface shall not exceed 10 ug/L.
- Total Phosphorus: a Carlson's TSI value for planktonic chlorophyll-*a* concentration in the water column is less than 62.

As stipulated in the Implementation Procedures for Oklahoma Water Quality Standards [785:46-15-3c], the most recent 10 years of water quality data are to be used as the basis for assessment of the water quality conditions and beneficial use support for a waterbody (OWRB, 2014). Tenkiller Ferry Lake was listed as impaired in the 2014 Integrated Report based on an analysis of 10 years of records for DO, chlorophyll-*a* and total phosphorus data collected by OWRB from October 2004 through May 2014.

OWRB provided data files used for analysis of the lake water quality data to support impairment determinations for the 2014 Integrated Report and 303(d) list. Inspection of the data sets showed that data were available from the Tenkiller Ferry Lake OWRB BUMP surveys for the period from August 1996 through July 2010.

Summary statistics presented in **Table 2.5** through **Table 2.7** are based on data collected by OWRB from 1996 to 2010. These data were used by OWRB for evaluation of the impairments of Tenkiller Ferry Lake.

Time series of chlorophyll-*a*, shown in <WHAT> are the data collected at the OWRB monitoring sites in the Illinois River Arm listed in (WHAT). The long-time average of chlorophyll-*a* concentration in the Illinois River Arm during 2003 to 2009 was 13.8 μg/L, higher than the ODEQ water quality standard of chlorophyll-*a* for TenKiller Ferry Lake, 10 μg/L. Hence, there is chlorophyll-*a* violation in the Illinois River Arm of Tenkiller Ferry Lake.

Table 2.5 Water Column Observations of Surface Chlorophyll-*a* at OWRB Stations (Site3, Site4, Site5, and Site6) in the Illinois River Arm of the Tenkiller Ferry Lake

Date	Water Column < 10 µg/l
Target-->	<10
OWRB Station	Site 3,4, 5, and 6
2003	10.0
2004	13.0
2005	16.1
2006	15.6
2009	14.2
Average	13.8

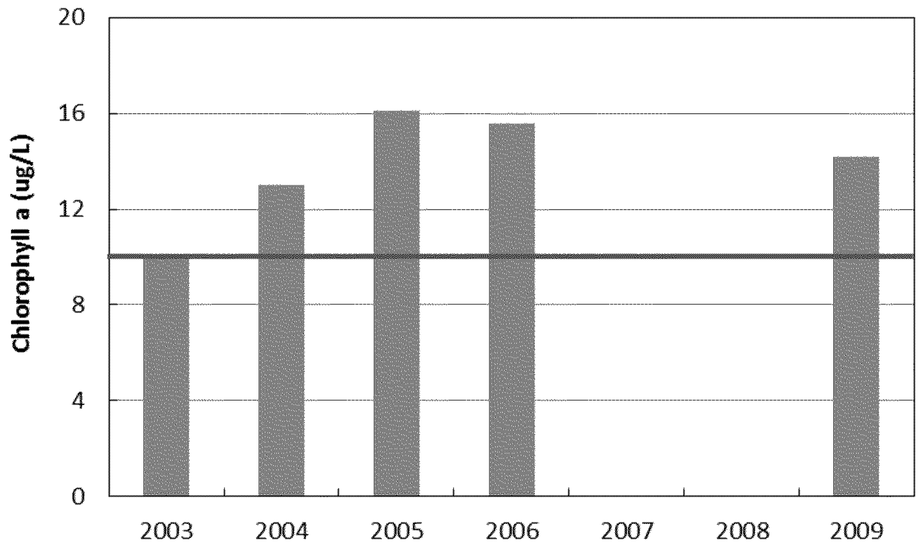


Figure 2.2 Water Column Observations of Surface Chlorophyll-*a* at OWRB Stations (Site3, Site4, Site5, and Site6) in the Illinois River Arm of Tenkiller Ferry Lake, during 2003 to 2009

Figure 2.3 presents surface to bottom water column data for dissolved oxygen for the OWRB station (Site1) located near the dam. A listing of the water quality data sets collected by the CDM/USGS in 2005-2006 that was used to support development of the watershed and lake models for this TMDL are presented in Appendix I.

Based on an assessment of water column dissolved oxygen data for the 2014 303(d) list, OWRB has determined that Tenkiller Ferry Lake is not fully supporting its beneficial uses for Fish and Wildlife Propagation because of the anoxic percentage of the water column of dissolved oxygen during summer conditions. As shown in **Table 2.6**, vertical profiles of dissolved oxygen collected at the OWRB station near the dam (Site1) showed that more than 70% of the water column was less than the 2 mg/L target for anoxia within the hypolimnion for two sampling surveys (July 15 2002 and July 20 2010) during the period from 1996-2010.

The Code of Federal Regulations [40 CFR §130.7(c)(1)] states that, "*TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards*." The water quality targets established for Tenkiller Ferry Lake must demonstrate compliance with the numeric criteria prescribed for Fish and Wildlife Propagation, Warm Water Aquatic Community and NLW lakes in the Oklahoma WQS.

Table 2.6 Water Column Observations of Dissolved Oxygen at OWRB Station (Site1) near the Dam in Tenkiller Ferry Lake

Date	Water Column < 2 mg/l
Target-->	<70%
OWRB Station	Site 1
08/14/1996	58.9%
10/06/1999	36.0%
01/05/2000	0.0%
04/10/2000	0.0%
05/04/2000	0.0%
06/27/2000	20.7%
10/15/2001	33.3%
01/14/2002	0.0%
04/15/2002	0.0%
07/15/2002	81.8%
09/15/2003	65.6%
12/15/2003	0.0%
03/15/2004	0.0%
06/14/2004	18.4%
10/03/2005	47.5%
01/23/2006	0.0%
04/24/2006	0.0%
07/24/2006	58.4%
12/08/2009	0.0%
01/26/2010	0.0%
04/21/2010	0.0%
07/20/2010	79.7%

Table 2.7 Observations of Dissolved Oxygen at OWRB Stations

Date	Early stages (4/1-6/15)	Other stages (6/16-3/31)
Target-->	> 6.0 mg/l	> 5.0 mg/l
OWRB Stations		
1996		8.5
1999		5.5
2000	9.0	8.9
2001		7.6
2002	9.6	9.1
2003		8.3
2004	10.9	11.4
2005		8.0
2006	7.9	10.1
2009		11.5
2010	12.9	11.4

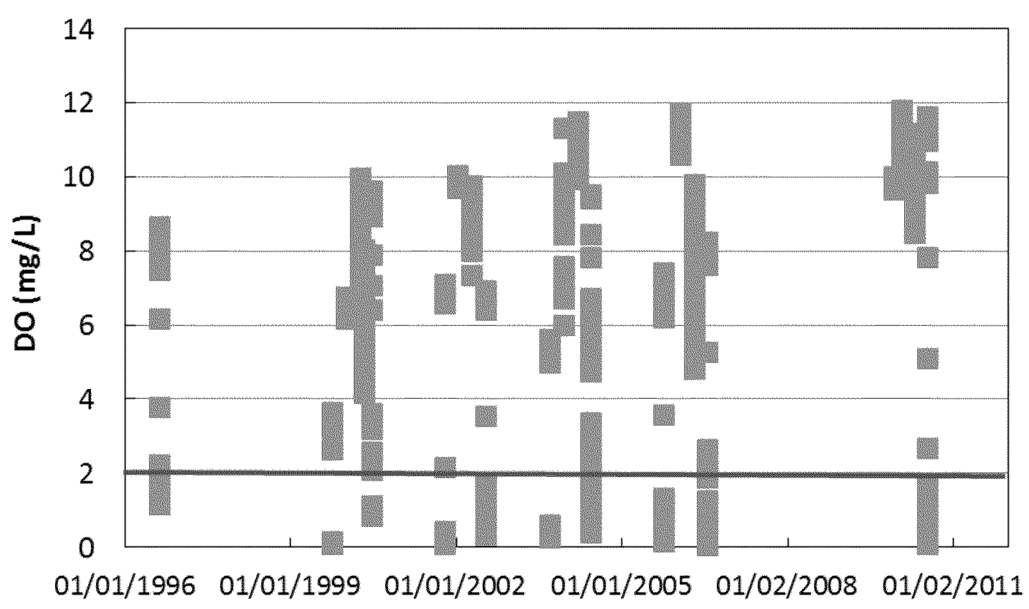


Figure 2.3 Water Column Observations of Dissolved Oxygen at OWRB Station near the Dam in Tenkiller Ferry Lake

SECTION 3. POINT SOURCE ASSESSMENT

This section includes an assessment of the known and suspected sources of nutrients, organic matter and sediments contributing to the water quality impairments of Illinois River tributaries and Tenkiller Ferry Lake. Pollutant sources identified are categorized and quantified to the extent that reliable information is available. Generally, sediment and nutrient loadings causing impairment of lakes originate from point or nonpoint sources of pollution. Point source discharges are regulated under permits through the NPDES program. Nonpoint sources are diffuse sources that typically cannot be identified as entering a waterbody through a discrete conveyance, such as a pipe, at a single location. Nonpoint sources may originate from rainfall runoff and landscape dependent characteristics and processes that contribute sediment, organic matter and nutrient loads to surface waters. For the TMDLs presented in this report, all sources of pollutant loading not regulated under the NPDES permit system are considered nonpoint sources.

Under 40 CFR, §122.2, a point source is described as an identifiable, confined, and discrete conveyance from which pollutants are, or may be, discharged to surface waters. NPDES-permitted facilities classified as point sources that may contribute sediment, organic matter and nutrient loading include:

- NPDES Municipal wastewater treatment plant (WWTP) discharges;
- NPDES Industrial WWTP discharges;
- Municipal no-discharge WWTPs;
- NPDES Municipal separate storm sewer system (MS4) discharges;
- Sanitary Sewer Overflows (SSO)
- NPDES Construction Site stormwater discharges;
- NPDES Multi-Sector General Permits (MSGP) stormwater discharges; and
- NPDES Concentrated animal feeding operations (CAFO)
- NPDES Poultry feeding operations (PFO)

All of the above listed types of permitted facilities are present in the Tenkiller Ferry Lake study area. Facilities under multi-sector general permits (MSGP), and NPDES permitted construction sites, which are regulated under the EPA NPDES Program, can all contribute sediment loading to the lake. Within the Tenkiller Ferry Lake watershed there are a number of construction site permits and multi-sector general permits that have been issued and will be addressed in Section 3.1.3 and 3.1.4 of this report. 40 CFR §130.2(h) requires that NPDES-regulated stormwater discharges must be addressed by the wasteload allocation (WLA) component of a TMDL assessment

3.1. Assessment of Point Sources

3.1.1 NPDES Municipal and Industrial Wastewater Facilities

Data on point sources discharges have been compiled from a number of different sources of information, including data provided by EPA, State representatives, and the dischargers. Prior modeling efforts focused on the major dischargers, and ignored the contributions from the numerous minor and smaller ones. A similar approach is followed in this effort as the detailed time series data needed is not available for the minor dischargers.

Point source loads have been developed for 13 primary facilities (Table **3.1**) that discharge to the Illinois River and its tributaries. The primary basis for developing the point source loads were (1) internal monitoring data provided by individual facilities (Springdale, Fayetteville, Lincoln, Rogers, Siloam Springs, Tahlequah, Stilwell) and (2) Discharge Monitoring Report (DMR) data provided by Oklahoma DEQ (Andrew Fang) and Arkansas DEQ. Bicknell and Donigian (2012) document the data, procedures, and assumptions that were used to develop the loads.

Table 3.1 Point Sources in Illinois River Watershed

NPDES #	Facility	Discharge Location	Typical
AR0022098	Prairie Grove, City of	Muddy Fork	0.3
AR0020010	Fayetteville - Paul Noland WWTP	Mud Ck	4.5
AR0050288	Fayetteville - Westside WWTP	Goose Ck	5.8
AR0033910	USDA FS - Lake Wedington Rec. Area	Tributary to Illinois R	0.0013
AR0035246	Lincoln, City of	Bush Ck/Baron Fork	0.45
AR0022063	Springdale WWTP, City of	Spring Ck/Osage Ck	12
AR0043397	Rogers, City of	Osage Ck	6.5
AR0020184	Gentry, City of	SWEPCO Res/L Flint Ck	0.45
AR0020273	Siloam Springs, City of	Sager Ck/Flint Ck	3
AR0037842	SWEPCO Flint Ck Power Plant	SWEPCO Res/Flint Ck	5/400 *
OK0026964	Tahlequah Public Works Authority	Tahlequah Ck	2.7
OK0028126	Westville Utility Authority	Shell Branch/Baron Fork	0.2
OK0030341	Stilwell Area Development Authority	Caney Ck	0.85
Add NACA			

* - Once-through cooling water outflow (400 MGD) and wastewater outflow (5 MGD)

3.1.2 NPDES Municipal Separate Storm Sewer System (MS4)

3.1.3 NPDES Construction Site Permits

3.1.4 NPDES Multi-Sector General Permits (MSGP) for Industrial Sites

3.1.5 NPDES Animal CAFOs

We may need to Currently there are no permitted CAFOs.

3.1.6 Missing Data

The general methodology for filling missing values was interpolation or averaging. Very little of the monthly data were missing. However, the daily/weekly data were filled in to generate daily time series by interpolation and averaging. Also, at the facilities where the monthly data did not extend over the entire period of point source data development (1990/1/1 - 2009/12/31), the existing data were extended back in time using selected averages of the existing data for that facility. For example, at the Lincoln facility, many of the constituents were not available prior to 2001, and were therefore estimated from the available data from 2001 through 2009. The procedures applied for filling in missing data at each facility are documented in Bicknell and Donigian (2012).

3.2. Assessment of Nonpoint Pollutant Sources

3.2.1 Atmospheric Deposition of Nutrients

Atmospheric deposition of nutrients is commonly included in watershed modeling efforts that focus on nutrient issues, like the current study. Atmospheric deposition data were obtained online through the National Atmospheric Deposition Program (NADP) (http://nadp.sws.uiuc.edu/) and the Clean Air Status and Trends Network (CASTNet) (http://java.epa.gov/castnet/). Sites in the NADP precipitation chemistry network began operations in 1978 with the goal of providing data on the amounts, trends, and geographic distributions of acids, nutrients, and base cations in precipitation. The network grew rapidly in the early 1980s funded by the National Acid Precipitation Assessment Program (NAPAP), established in 1981 to improve understanding of the causes and effects of acidic precipitation. Reflecting the federal NAPAP role in the NADP, the network name was changed to NADP National Trends Network (NTN). The NTN network currently has 250 sites.

CASTNet began collecting measurements in 1991 with the incorporation of 50 sites from the National Dry Deposition Network, which had been in operation since 1987. CASTNET provides long-term monitoring of air quality in rural areas to determine trends in regional atmospheric nitrogen, sulfur, and ozone concentrations and deposition fluxes of sulfur and nitrogen pollutants in order to evaluate the effectiveness of national and regional air pollution control programs. CASTNET operates more than 80 regional sites throughout the contiguous United States, Alaska, and Canada. Sites are located in areas where urban influences are minimal. The primary sponsors of CASTNET are the Environmental Protection Agency and the National Park Service.

The data available from NADP/NTN are wet deposition of NH4 and NO3 in the form of precipitation-weighted concentrations (mg-N/L) on a monthly basis from 1980-2009. There are two active stations near the watershed: one is in Fayetteville, AR, and the other is in McClain County, OK. Two inactive stations in Oklahoma at Lake Eucha and Stilwell have data only for a limited period (2000-2003). There are no phosphorus data available.

The CASTNet data available for the watershed are weekly, quarterly, seasonal, and annual dry deposition fluxes of NH4, HNO3, and NO3- for 10/88-12/09. The stations near the watershed are Cherokee Nation in Adair County, OK and Caddo Valley in Clark County, AR. The Caddo Valley station is near an NADP station, but not the Fayetteville station.

There are very little data available to estimate phosphorus deposition. Most of the literature concludes that atmospheric deposition is a small contributor to the total P budget. Based on the available data and literature, we assume that atmospheric deposition of phosphorus is negligible compared to other sources.

3.2.2 Agricultural Land uses

3.2.3 On-site Sewage

3.2.4 Other Anthropogenic Sources

3.2.5 Watershed Loading of Nutrients and Sediment

Watershed loading results from precipitation and hydrologic runoff processes over drainage area catchments that are dependent on characteristic properties of the landscape such as topography, land use, soil types and physical processes such as infiltration and erosion. Flow and pollutants, derived from watershed runoff, are transported through a network of streams and rivers with discharge into the lake at downstream outlets of the streams. As the watershed loading of nutrients usually is a significant component of the overall nutrient loading to a waterbody, loading from the watershed to the lake is considered as a controllable source term for a TMDL determination.

Runoff and pollutant loading of nutrients and sediments from the modeled drainage basin into Tenkiller Ferry Lake is estimated using a public domain and peer reviewed watershed model, Hydrologic Simulation Program-FORTRAN (HSPF). An overview description of the application of the HSPF watershed model for the Tenkiller Ferry Lake project is presented in Section 3.3 of this report. A more complete description of the watershed model is given in Appendix B of this report.

3.2.6 Internal Lake Loading from Benthic Nutrient Release

In addition to the external loading of nutrients from watershed runoff and atmospheric deposition into the lake, decomposition processes in the sediment bed can also contribute a significant internal load of nutrients to the overall nutrient loading to the lake and contribute to eutrophication of the lake. Particulate organic matter in the water column and sediment bed of Tenkiller Ferry Lake is derived from both external wastewater sources and watershed runoff and internal biological production of organic matter. Particulate organic matter settles out of the water column, accumulates within the sediment bed, and undergoes decomposition processes. During the period of thermal stratification, decay processes within the sediment bed deplete dissolved oxygen below the thermocline and release inorganic nutrients from the sediment bed back into the water column. The release of ammonia and phosphate from the bed to the water column, in particular, is controlled, in part, by bottom water dissolved oxygen levels with the largest internal release rates occurring during summer anoxic conditions. This internal source of nutrients is considered to be an uncontrollable source term for the TMDL determination in this study. Nevertheless, just like atmospheric deposition of nutrients, lake water quality models that simulate the nutrient balance of the lake must account for this internal source of nutrients as a contributing factor for eutrophication and the mass balance of nutrients.

Site-specific measurements of nutrient release from the sediment bed under aerobic and anoxic conditions in Tenkiller Ferry Lake are available in the summer of 2016 reported by Lasater and Haggard (2017). Benthic nutrient release data are also available from some lakes and reservoirs in the region such as Lake Wister (Haggard and Scott, 2011); Lake Frances (Haggard and Soerens, 2006); Lake Eucha (Haggard et al., 2005) in Oklahoma; Beaver Lake in Arkansas (Sen et al., 2007; Hamdan et al., 2010), Acton Lake in Ohio (Nowlin et al., 2005) and a group of 17 lakes and reservoirs in the Central Plains (Dzialowski and Carter, 2011). Benthic phosphate release rates, characteristic of eutrophic lakes and reservoirs, can also be estimated for Tenkiller Ferry Lake using an empirical methodology developed by Nurnberg (1984). Measured phosphate release data collected by Lasater and Haggard (2017) were used to confirm model results simulated by the internally coupled sediment diagenesis sub-model of the EFDC lake model that was developed for Tenkiller Ferry Lake.

SECTION 4. MODELING APPROACH

In order to develop a scientifically sound modeling system to represent the entire IRW, including the land areas, the stream channels and Lake Tenkiller, models must be selected to represent each of these components. If the selected models are not already integrated within a single modeling system, the models must be linked to provide a comprehensive tool that addresses the watershed hydrology, generation of pollutants, fate/transport within the stream system, and ultimately dynamics and impacts on Tenkiller Ferry Lake.

As part of the study effort, a model selection task was performed and produced a Draft Model Selection Technical Memorandum dated November 22, 2010 (Donigian and Imhoff, 2010). This model comparison and selection process resulted in the recommendation that the US EPA HSPF (Hydrological Simulation Program – FORTRAN (Bicknell et al., 2005)) watershed model and the US EPA EFDC (Environmental Fluid Dynamics Code (Hamrick 1992, 1996; Tetra Tech, 2007) lake model be used in a linked application to provide the necessary modeling framework for performing this study. Following review and comments from project stakeholders, EPA subsequently agreed to the model recommendations and selected the HSPF watershed model and the EFDC lake model for this TMDL effort (M. Flores, personal communication, email to Project Stakeholders dated January 13, 2011).

HSPF was selected for the watershed because it provides a strong dynamic (i.e. short time step, hourly) hydrologic and hydraulic model simulation capability, and a moderately complex instream fate/transport simulation of sediment and phosphorus, both of which are linked to soil nutrient and runoff models; this combination provides a strong and established capability to relate upstream watershed point and nonpoint source contributions to downstream conditions and impacts at both the AR/OK state line and to Lake Tenkiller.

EFDC was selected because it allows a more mechanistic modeling of thermal stratification and is capable of a high level of spatial resolution in Lake Tenkiller, both of which are essential to support water quality compliance issues in OK, particularly time- and space-varying anoxic conditions. EFDC also provides moderately complex *biochemical* process representation that enables modeling and evaluation of chlorophyll-*a* concentrations expressed as Carlson's Trophic State Index (TSI). Oklahoma statutes use TSI values to determine whether or not water bodies are threatened by nutrients. The EFDC water quality model is internally coupled to a sediment diagenesis model (Di Toro, 2001) so that the effect of external nutrient loading on organic matter production and settling to the bed, decomposition within the bed, sediment oxygen demand and benthic release of nutrients to the lake can be simulated within a consistent mass balance model framework. The sediment diagenesis model is the only lake model methodology available to provide a simulated cause-effect link between watershed loading, nutrient enrichment, eutrophication, sediment oxygen demand and internal release of nutrients from the lake bed back to the water column.

4.1. HSPF Watershed Model

4.1.1 HSPF Model Overview Description

HSPF is a continuous watershed simulation model that produces a time history of water quantity and quality at any point in a watershed. HSPF is an extension and reformulation of several previously developed models: the Stanford Watershed Model (SWM) (Crawford and Linsley, 1966), the Hydrologic Simulation Program (HSP) including HSP Quality (Hydrocomp, 1977), the Agricultural Runoff Management (ARM) model (Donigian and Davis, 1978), and the Nonpoint Source Runoff (NPS) model (Donigian and Crawford, 1977). This Section 4.1 is a summary of the HSPF Model application to the IRW for TMDL development; the HSPF application to the IRW watershed is fully described in the original model report (MBI et al., 2015)

4.1.2 Segmentation, Characterization, and Setup of HSPF Model

4.1.2.1 ***Watershed Boundaries***

Whenever any watershed model is set up and applied to a watershed, the entire study area must undergo a process sometimes referred to as 'segmentation'. The purpose of watershed segmentation is to divide the study area into individual land and channel segments, or pieces, that are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. This segmentation provides the basis for assigning similar or identical input and/or parameter values or functions to where they can be applied logically to all portions of a land area or channel length contained within a model segment. Since most watershed models differentiate between land and channel portions of a watershed, and each is modeled separately, each undergoes a segmentation process to produce separate land and channel segments that are linked together to represent the entire watershed area.

The results of the land segmentation process are a series of model segments, sometimes call hydrologic response units (HRUs) that demonstrate similar hydrologic and water quality behavior. Over the past few decades, geographic information systems (GIS), and associated software tools, have become critical tools for watershed segmentation. Combined with advances in computing power, they have allowed the development of automated capabilities to efficiently perform the data-overlay process. GIS data used in the segmentation process that affect the hydrologic and water quality response of a watershed are: topography and elevation, hydrography/drainage patterns, land use and land cover, soils information, and other various types of spatial data.

The primary sources for GIS data obtained for the IRW were those accessed through the use of the BASINS data download capability, from the SWAT 2009 modeling files provided by OK DEQ, and additional data provided by stakeholders in response to the Federal Register data request. Through the BASINS interface a wide range of GIS data layers were downloaded and displayed. BASINS accesses GIS data from a variety of sources such as The National Land Cover Data (NLCD), National Hydrography Dataset (NHD), and the USGS seamless data server (http://seamless.usgs.gov/). Other sources include the earlier HSPF modeling efforts, Geospatial One-Stop (http://gos2.geodata.gov/wps/portal/gos), and contacts with the OK DEQ and AR DEQ. Geospatial One-Stop is an e-government initiative sponsored by the Federal Office of Management and Budget (OMB) to make it easier, faster, and less expensive for all levels of government and the public to access geospatial information

Following subsections describe the major categories of GIS data used in model segmentation, and describe the model segmentation of the IRW.

4.1.2.2 ***Topography***

GIS layers of topography provide elevation and slope values for the project area, and are needed for characterizing the landscape and the land areas of the watershed. These elevation values are used to delineate subbasins, determine average elevations for each model subbasin, and/or to compute average slopes for model subbasins and land uses within a subbasin.

The National Elevation Dataset (NED) available through BASINS 4.0 with a resolution of 30-meter as Digital Elevation Model (DEM) grid with vertical units in centimeters was used for the topography. This was augmented by 10-meter resolution DEM, available from the USGS seamless site; was used in the lower slope areas for better spatial resolution, as needed. The topography information for IRW is shown in Figure 4.1.

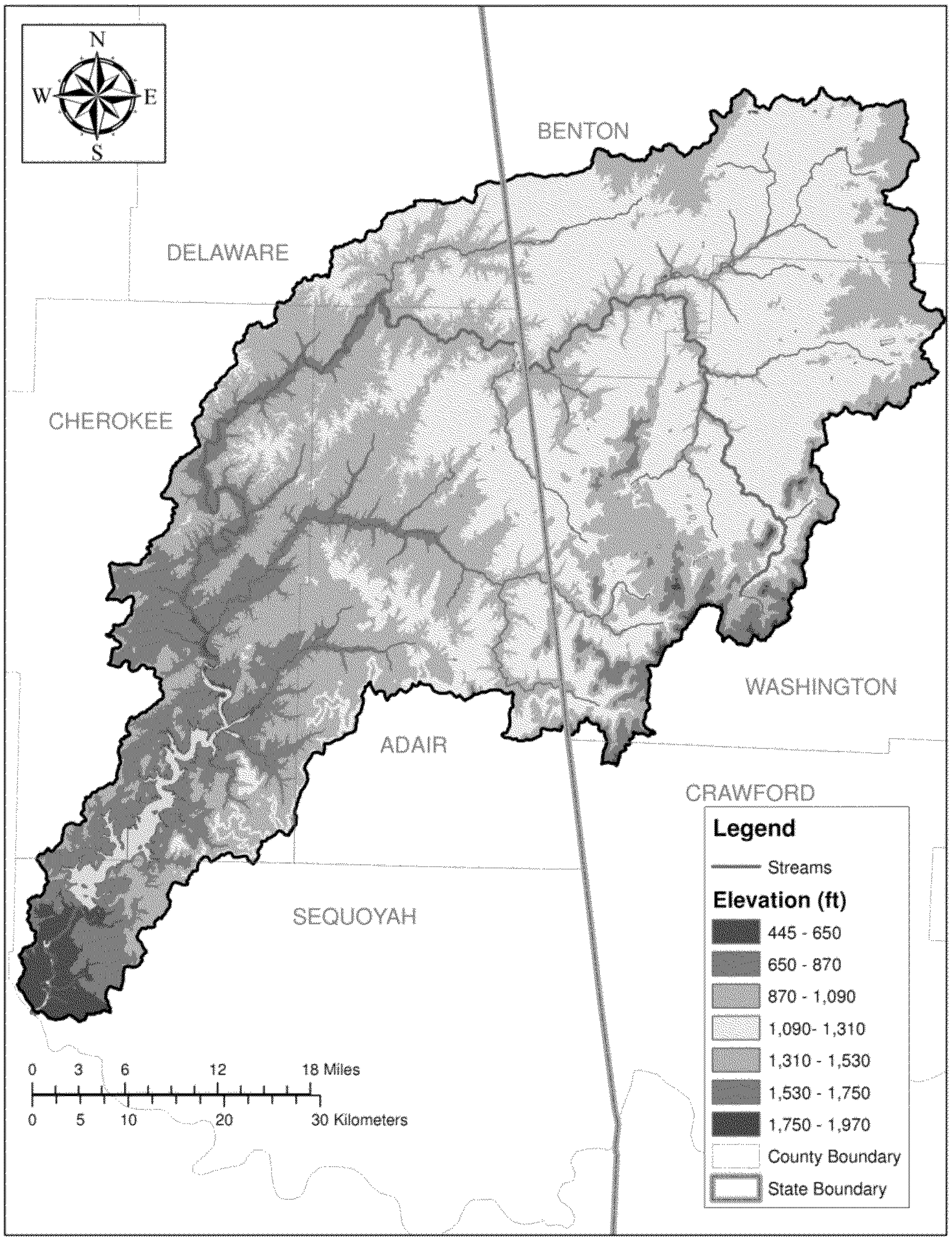


Figure 4.1 Topographic Data Derived from a 10-Meter DEM from the USGS Seamless Server

4.1.2.3 **Soils**

Soils data is used to characterize the infiltration and soil moisture capacity characteristics of the watershed soils, along with the erodibility parameters for soil erosion. SSURGO (Soil Survey Spatial and Tabular Data) soils data for the IRW were downloaded from the USDA/NRCS Data Gateway site (http://soildatamart.nrcs.usda.gov/). SSURGO depicts information about the kinds and distribution of soils on the landscape. This dataset is a digital soil survey and generally is the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. This dataset consists of georeferenced digital map data, computerized tabular attribute data, and associated metadata.

The properties of this dataset of interest in this watershed modeling study are: soil description, slope gradient, water table depth, flooding frequency, available water storage, hydrologic group, and hydric group. Spatial data on the SCS Hydrologic Soil Groups (HSG) were obtained and used to generate a map of the spatial distribution of these properties, shown in Figure 4.2. The HSG B, C, and D distributions by subwatershed will be used as a basis for model parameterization related to infiltration and soil moisture capacity values in the model.

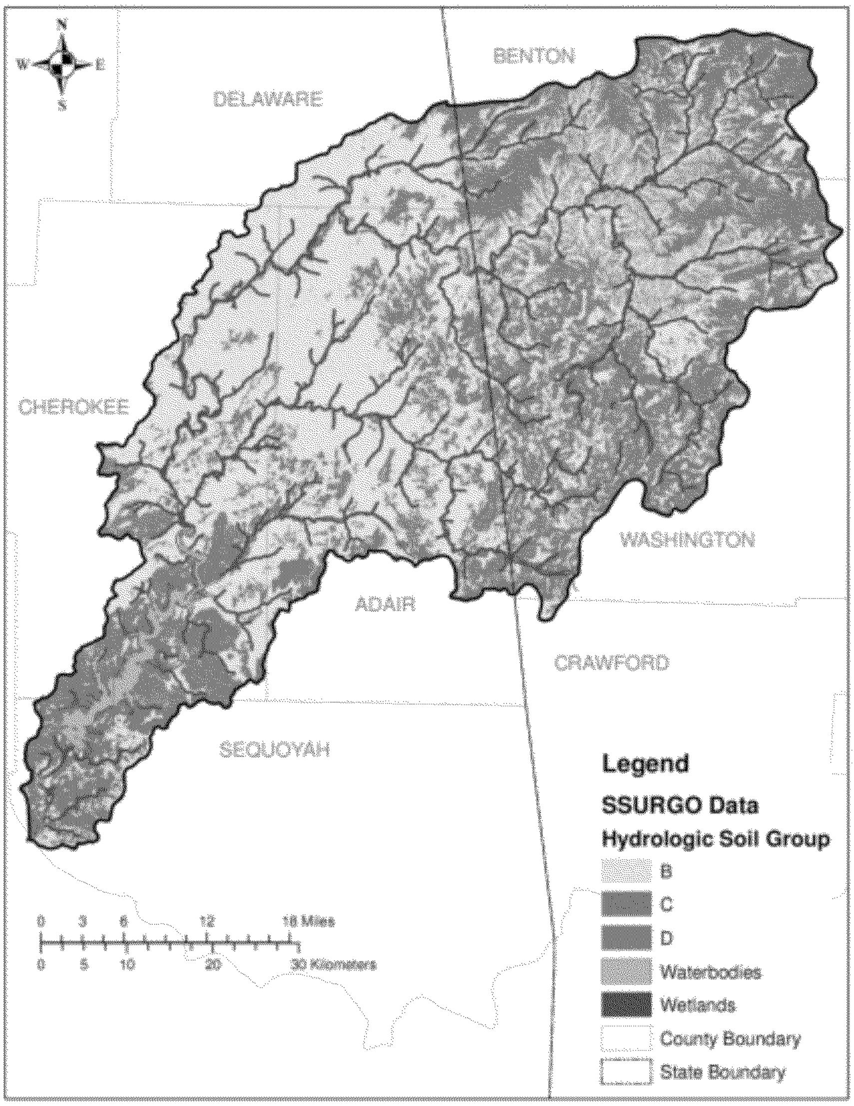


Figure 4.2 Distribution of NRCS Hydrologic Soil Groups for the IRW

4.1.2.4 **Land Use**

Land use, or land cover, data is a critical factor in modeling complex multi-land use watersheds as it provides the detailed characterization of the potentially primary source of pollutants entering the streams and rivers as nonpoint source contributions. In addition, the land use distribution has a major determining impact on the hydrologic response of the watershed.

As discussed in the Data Report, a number of sources of land use data were investigated but, at that time, no single, consistent coverage, spanning both States, existed for the entire IRW other than the 2001 NLCD. Fortunately, in early 2011, the 2006 NLCD data was released and provided the consistent recent coverage needed covering both States, and applicable to a relatively recent time period with significant available water quality data. Table 4.1 lists the land use categories and distributions for the 1992, 2002, and 2006 NLCD, while Table 4.2 shows the correspondence between the NLCD categories and the model categories. Figure 4.3 shows and compares the spatial distribution of the NLCD categories for the 2001 and 2006 data layers.

Both Table 4.1 and Table 4.2 are color-coded to identify likely groupings of land uses with similar characteristics, with dark green showing forest categories, light brown for grasslands and shrub/scrub, pink for urban developed categories, etc. Comparing the category distributions for the three different time periods indicates the following:

1. There are some obvious inconsistencies between 1992 and the more recent 2001 and 2006 distributions, most likely due to differences in classifications within categories. For example, there is a big increase in grassland/herbaceous from 1991 to 2001, and a comparable decrease in cultivate cropland. Although cropland likely did decrease, the amount of the decrease indicates a classification issue.
2. Forest distributions between 1992 and 2001 also show a big jump in deciduous and decreases in both evergreens and mixed categories. However, the differences between 2001 and 2006 are relatively small and in the expected directions.
3. Developed land shows a decrease in the high and medium intensity categories, and then a big jump in the developed open space category, most likely due to a classification change. The changes in developed categories between 2001 and 2006 are more consistency and in the expected direction.
4. Overall, the land use distributions for 2001 and 2006 shown in Table 4.1 appear to be consistent, with modest changes and in the expected direction.

Based on this review of the NLCD data, the coverages for 2001 and 2006 appeared to be the most consistent and reliable, representative land use data layers for use in modeling the IRW. The Data Report also noted the availability of the USDA-NASS Cropland Data Layer (CDL) as a potential source of recent land use data, and digital orthophotos available from the State of Oklahoma. In addition, since the Data Report was submitted, land use coverages for the Arkansas portion of the IRW were obtained from the University of Arkansas Center for Advanced Spatial Technologies (CAST) for a number of years from 2003 to 2009. All of these additional land use data layers were available for refinements or adjustments to the NLCD coverage, as needed, for use in the watershed modeling.

Table 4.2 lists the 15 NLCD land use categories and their percentages for both 2001 and 2006, along with the aggregation of these categories into the eight categories that are simulated by the watershed model; the Open Water category is listed in Table 4.2 but its area is included in the model as the surface area of streams and lakes. The practice of aggregating

GIS land use categories for modeling is common in watershed modeling, depending on study objectives and details of the GIS layers. Small percentages of a land use category, such as evergreen and mixed forests in Table 4.2, are lumped with the dominant category, with similar land use/land cover characteristics for modeling, such as deciduous forests in Table 4.2. It is often difficult to distinguish and quantify model parameter values for such similar categories with only slightly different characteristics. In a similar manner, grasslands, shrub/scrub and barren are combined into one category, and the wetland categories are combined into another. Since projecting the impacts of future urbanization is a common use of watershed models, the developed categories are mostly left intact. One exception is combining the medium and high intensity classes since these are often small fractions of the total area, and the difference between them is arbitrary in many cases.

Once the model was calibrated for hydrology and water quality, the 2011 NLCD data was released. The model was updated using the 2011 NLCD data to represent the baseline conditions.

Table 4.1 Distribution of NLCD Land Use for 1992, 2001, and 2006

	1992		2001-v2		2006	
Description	Area (Sq. Mi.)	% Land Use	Area (Sq. Mi.)	% Land Use	Area (Sq. Mi.)	% Land Use
Deciduous Forest	555.98	33.63	684.66	41.40	679.64	41.11
Evergreen Forest	33.96	2.05	19.79	1.20	19.62	1.19
Mixed Forest	114.88	6.95	8.14	0.49	8.09	0.49
Pasture/Hay	769.13	46.52	693.31	41.92	679.15	41.08
Grassland/Herbaceous	0.21	0.01	56.38	3.41	60.05	3.63
Shrub/Scrub	13.56	0.82	7.69	0.46	8.27	0.50
Barren land (rock/sand/clay)	3.30	0.20	1.86	0.11	3.20	0.19
Developed, Open Space	7.50	0.45	92.85	5.61	97.99	5.93
Developed, Low Intensity	28.66	1.73	35.66	2.16	39.93	2.41
Developed, Medium Intensity	13.69	0.83	12.23	0.74	15.22	0.92
Developed, High Intensity	12.34	0.75	4.76	0.29	5.73	0.35
Woody Wetlands	5.04	0.31	9.75	0.59	9.73	0.59
Emergent Herbaceous Wetlands	1.63	0.10	0.12	0.01	0.12	0.01
Cultivated Crops	61.14	3.70	2.55	0.15	2.45	0.15
Open Water	32.34	1.96	24.13	1.46	24.15	1.46
Total	1653.35	100.00	1653.87	100.00	1653.35	100.00

Table 4.2 Aggregation of NLCD Land Use to Model Categories

NLCD Class (2001, 2006)	2001 Percent	2006 Percent	Aggregated Model Categories	2001 Percent	2006 Percent
Deciduous Forest	41.40%	41.11%			
Evergreen Forest	1.20%	1.19%	Forest	43.09%	42.78%
Mixed Forest	0.49%	0.49%			
Pasture/Hay	41.92%	41.08%	Pasture/Hay	41.92%	41.08%
Grassland/Herbaceous	3.41%	3.63%			
Shrub/Scrub	0.47%	0.50%	Grass/Shrub/Barren	3.99%	4.33%
Barren Land (Rock/Sand/Clay)	0.11%	0.19%			
Developed, Open Space	5.61%	5.93%	Developed, Open Space	5.61%	5.93%
Developed, Low Intensity	2.16%	2.42%	Developed, Low Intensity	2.16%	2.42%
Developed, Medium Intensity	0.74%	0.92%	Developed, Medium/High Intensity		
Developed, High Intensity	0.29%	0.35%	(includes Commercial/Industrial)	1.03%	1.27%
Woody Wetlands	0.59%	0.59%			
Emergent Herbacious Wetlands	0.01%	0.01%	Wetlands	0.60%	0.60%
Cultivated Crops	0.15%	0.15%	Cultivated Crops	0.15%	0.15%
Open Water	1.46%	1.46%	Open Water**	1.46%	1.46%
Totals	100%	100%	Totals	100%	100%

** - Open Water modeled as a water surface (stream/lake), not a land component

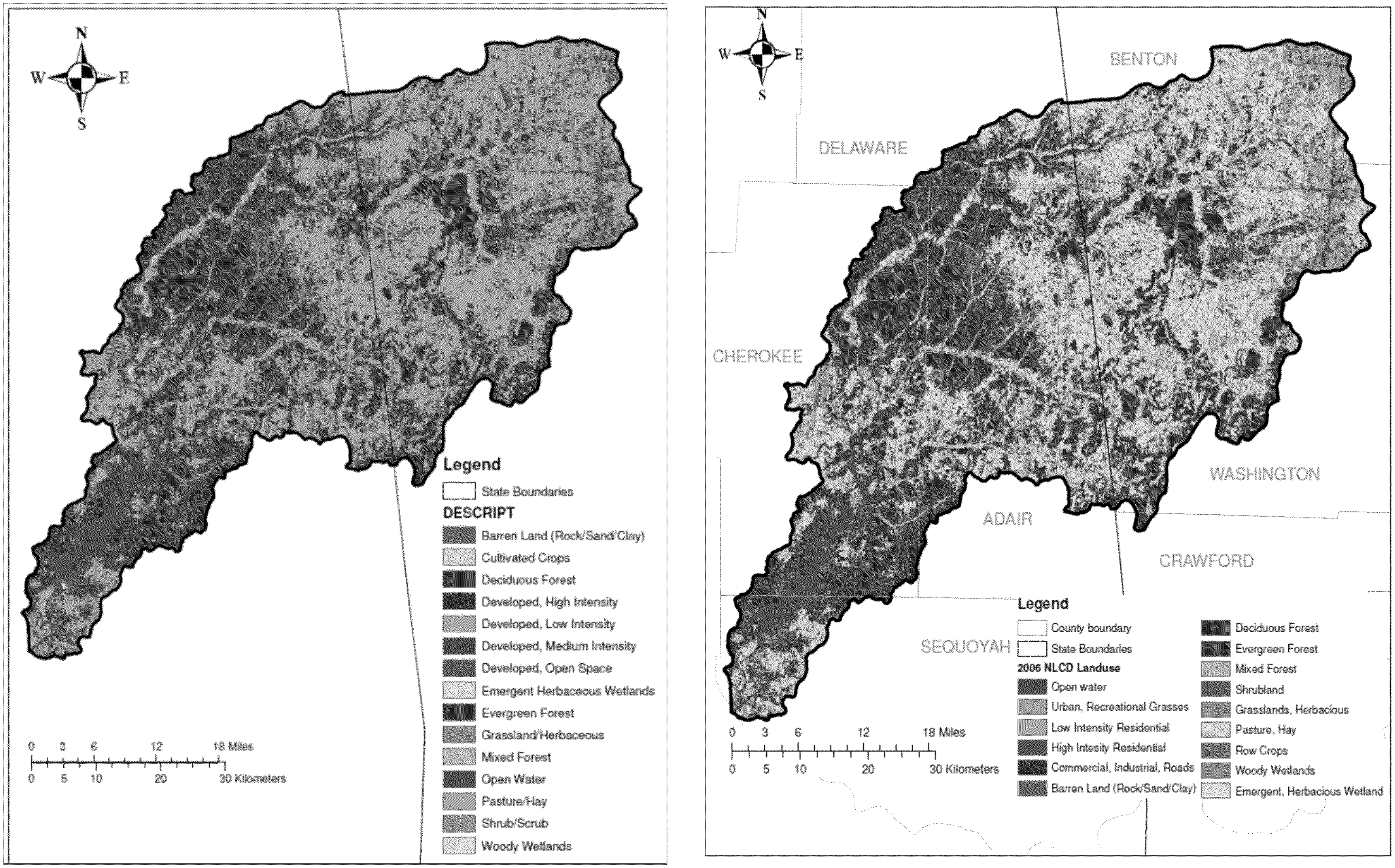


Figure 4.3 National Land Cover Data (NLCD) for 2001 and 2006

4.1.2.4.1 Effective Impervious Area

Effective Impervious Area, or EIA, is important to accurately represent in watershed models because of its impact on the hydrologic processes occurring in urban environments. The term "effective" implies that the impervious region is directly connected to a local hydraulic conveyance system (e.g., gutter, curb drain, storm sewer, open channel, or river) and the resulting overland flow will not run onto pervious areas and, therefore, will not have the opportunity to infiltrate along its respective overland flow path before reaching a stream or waterbody.

The EIA for the IRW will be represented using the NLCD 2001 v2 and NLCD 2006, as described above, but with specific focus on the Percent Imperviousness grid layers from those coverages. However, the NLCD Percent Imperviousness grids represent total impervious area (TIA), and it is important to address the distinction, and difference between TIA and EIA. EIA is always less than or equal to TIA.

For the IRW, the process for estimating the EIA for each land use involves first calculating the TIA of each developed urban land use category by overlaying the land use data over the impervious area grid, thus computing the impervious area (i.e., TIA) within each developed land use category. A summary of the results for the IRW, and for both the NLCD 2001 v2 and NLCD 2006 are shown in **Table 4.3**

Table 4.3 Total Impervious Areas (TIA) and Percent Imperviousness of Each Urban Land Use for NLCD 2001 v2, and NLCD 2006, and Calculation of EIA

	NLCD 2001		NLCD 2006		Average			
Land use Category	Impervious Area (ac)	TIA, %	Impervious Area (ac)	TIA, %	Total	TIA, %	EIA/TIA Ratio, %	Estimated EIA, %
Developed, Open Space	4,051	6.8	4,268	6.8	4,160	6.8	30	2
Developed, Low Intensity	6,953	30.5	7,785	30.5	7,369	30.5	45	14
Developed, Medium Intensity	4409	56.4	5309	54.5	4,859	55.5	55	30
Developed, High Intensity	2454	80.5	2844	77.9	2,649	79.2	80	63
Total	17,867	19.2	20,206	19.9	19,037	19.6		

In order to convert these TIA values to the EIA values needed for use in the HSPF model, we used data and studies presented by Laenen (1980, 1983), as reported by Sutherland (1995). Sutherland (1995) also describes a number of methods and formulas for calculating EIA from TIA, using equations such as the following:

$$EIA = 0.1(TIA)^{1.5} \qquad \textbf{3.1}$$

The equations provided by Sutherland however, are not distinguished, or defined separately, for individual urban land use categories. Therefore, using the Sutherland EIA-TIA curves, we estimated the EIA/TIA ratio for each of the developed urban land use categories for the IRW, based on their TIA values in Table 3.3, and then used these ratios to calculate the Estimated EIA for each developed land use category.

The last two columns of Table 4.3 show the EIA/TIA ratios and the resulting 'Estimated EIA Percent' value (last column) for each developed category. The final step was to calculate a weighted value for our combined 'High/Medium Intensity' category, using an assumed distribution of 70% Medium Intensity and 30% High Intensity uses; this produced a weighted

EIA value of 40% for the combined category. Table 4.4 shows the final EIA values assigned for the urban developed land use categories defined in the model for the IRW.

Table 4.4 Effective Impervious Area Percentage in Developed Land Use Classes in the IRW

Urban Land Use Category	EIA, %
Developed, Open Space	2
Developed, Low Intensity	14
Developed, Medium and High Intensity	40

These same EIA values will be used for 2006 NLCD land uses as well. During the BASINS UCI (Users Control Input) generation process, these EIA percentages are multiplied by the area of each corresponding developed NLCD category to compute the areas of the developed IMPLND and PERLND model categories. The model setup plug-in for HSPF in BASINS 4.0 allows entry of this data through the user interface.

These EIA values are reasonable and consistent with past HSPF applications performed by AQUA TERRA, and the calibration effort did not uncover or demonstrate a need to revise or adjust these values. These values assigned by land use category, and this approach, provide the added benefit of being able to estimate EIA values for future land use changes and scenarios related to urban growth and development.

4.1.2.5 ***Streamflow Data***

Flow data is needed for both calibration and validation of the watershed model to ensure it is reproducing the hydrologic behavior of the IRW, and providing proper boundary inflows into Lake Tenkiller, along with its transport of sediment and water quality constituents. The BASINS download capability provided the means to access all the USGS flow (and water quality) data for sites in the watershed. Figure 4.4 shows the locations of the USGS gaging sites within the watershed, and **Table 4.5** lists their names, USGS ID numbers, periods of record, tributary areas, and elevations for selected sites. In addition, the Arkansas Water Resources Center (B. Haggard, personal communication, 2011) provided supplemental data for Ballard Creek and Moore's Creek for model application.

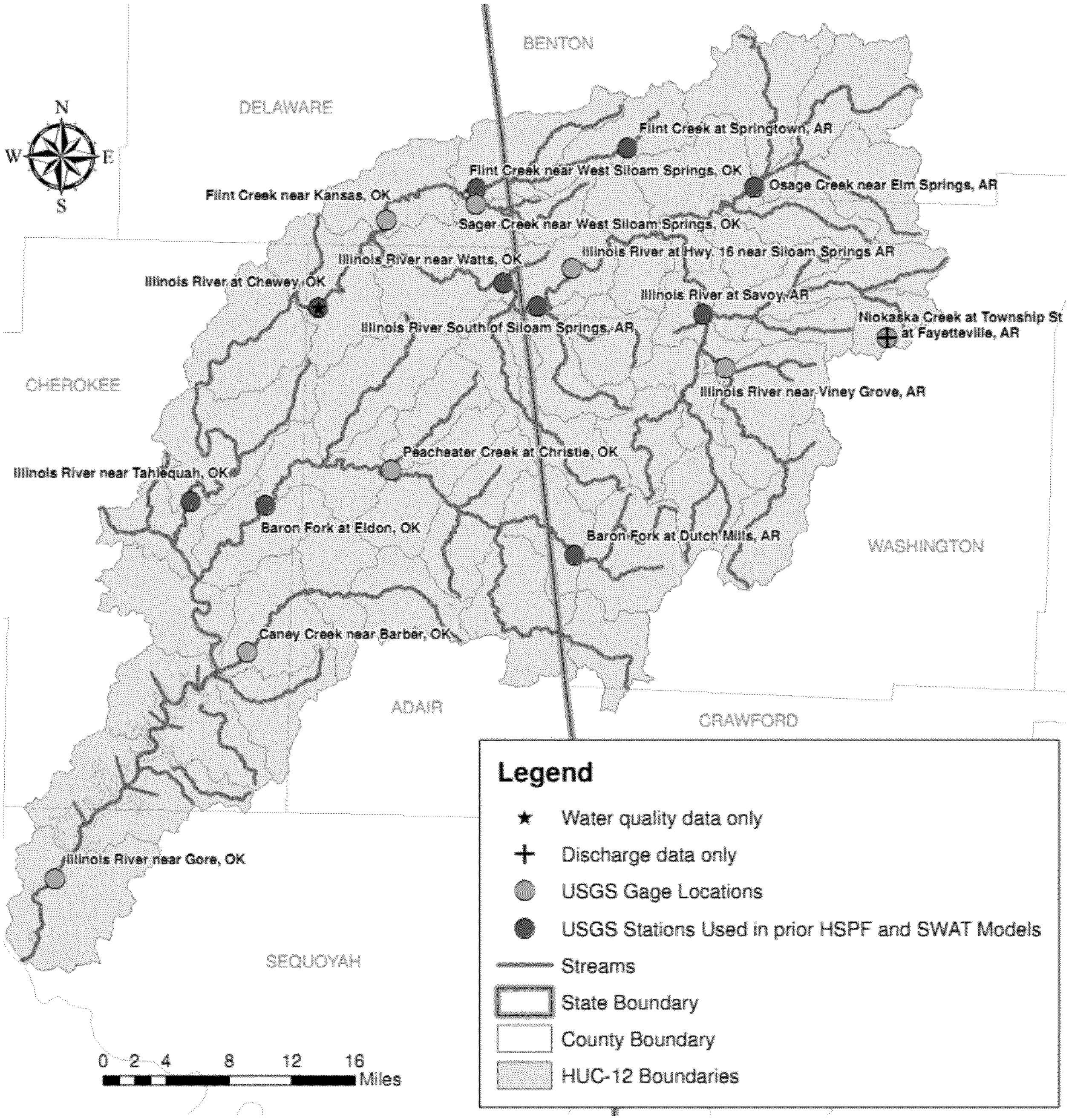


Figure 4.4 USGS Stream Gage Locations in the IRW

The USGS sites designated with red circles (●) are those used for model calibration and/or validation in the previous HSPF and SWAT model applications discussed above. However, no single model included ALL the gages shown in both states, until the current IRW modeling effort. Section 4 addresses the issue of selection of calibration/validation sites in both states, and the corresponding time periods. There are adequate periods of record for three to five calibration sites within each state, as discussed in Section 4.

Table 4.5 USGS Stream Gages Containing Flow Data

Location	Gage Station	Period of Record		Tributary Area (mi^2)	Elevation (ft)
Illinois River near Tahlequah, OK	07196500	10/1/1935	present	959.0	664
Baron Fork at Eldon, OK	07197000	10/1/1948	present	307.0	701
Baron Fork at Dutch Mills, AR	07196900	4/1/1958	present	40.6	986
Illinois River near Watts, OK	07195500	10/1/1955	present	635.0	894
Illinois River near Viney Grove, AR	07194760	9/5/1985	10/16/1986	80.7	1051
Illinois River at Savoy, AR	07194800	6/21/1979	present	167.0	1019
Niokaska Creek at Township St at Fayetteville, AR	07194809	9/19/1996	present	1.2	1482
Osage Creek near Elm Springs, AR	07195000	10/1/1950	present	130.0	1052
Illinois River at Hwy. 16 near Siloam Springs AR	07195400	6/21/1979	2/7/2011	509.0	1170
Illinois River South of Siloam Springs, AR	07195430	7/14/1995	present	575.0	909
Flint Creek at Springtown, AR	07195800	7/1/1961	present	14.2	1173
Flint Creek near West Siloam Springs, OK	07195855	10/1/1979	present	59.8	954
Sager Creek near West Siloam Springs, OK	07195865	9/12/1996	present	18.9	960
Flint Creek near Kansas, OK	07196000	10/1/1955	present	110.0	855
Peacheater Creek at Christie, OK	07196973	9/1/1992	9/16/2004	25.0	802
Caney Creek near Barber, OK	07197360	10/1/1997	present	89.6	638
Illinois River near Gore, OK	07198000	3/25/1924	present	1626.0	468

4.1.2.6 ***Water Quality***

Water quality data is used primarily for model calibration and validation, but also to help quantify source contributions and boundary conditions, such as for point sources, selected agricultural sources, and atmospheric deposition. A number of agencies contributed a wide variety water quality related data to be used in this effort. The Draft Data Report (AQUA TERRA Consultants, 2010b) listed the specific sites and constituents available, along with the period of record for each site and constituent, to support the model application.

The specific constituents modeled in this study include all constituents needed for modeling nutrients, with a specific focus on phosphorus species. The following list shows the conventional constituents that are modeled whenever nutrients are the purpose of a modeling effort:

1. Flow/discharge
2. TSS
3. water temperature
4. DO
5. BOD ultimate, or total BOD
6. NO3/NO2, combined
7. NH3/NH4
8. Total N
9. PO4
10. Total P
11. Phytoplankton as Chl a
12. Benthic algae (as biomass)

These are the constituents that are modeled for the IRW; they include flow and TSS as the basic transport mechanisms for moving the nutrients, along with the environmental conditions (e.g. temperature) and other state variables (e.g. DO/BOD), that are involved in the aquatic fate, transport, and cycling of nutrients in aquatic systems.

For most modeling efforts of moderate to large watersheds, the USGS is the primary source of both flow and water quality data. In the IRW, the USGS works collaboratively with both the OK DEQ and AWRC for flow and water quality data collection efforts. Data was obtained from both the USGS NWIS system through direct downloading, along with files provided by the state agencies. **Table 4.6** lists the USGS flow gages that also include water quality data, along with their period of record. The Data Report provides a compilation of the number of data points and their period of record for each relevant water quality constituent, at each water quality observation gage.

As a supplement to the USGS water quality data, the AR Water Resources Center (AWRC) provided a series of annual reports, along with spreadsheets of loading calculations, for four sites within the AR portion of the IRW (B. Haggard, personal communication, 25 May 2010). Daily loads are available for the IR at Highway 59 (USGS gage #07195430), Ballard Creek, Moore's Creek, and Osage Creek, and for various time periods from 1999 to 2009 (see Nelson et al., 2006 as an example annual report).

Table 4.6 USGS Stream Gages with Water Quality Data in the IRW

Location	Gage Station #	Period of Record		Tributary Area (mi^2)	Elevation (ft)
Illinois River near Tahlequah, OK	07196500	8/23/1955	12/15/2009	959	664
Baron Fork at Eldon, OK	07197000	5/7/1958	12/14/2009	307	701
Baron Fork at Dutch Mills, AR	07196900	3/17/1959	8/25/2009	40.6	986
Illinois River near Watts, OK	07195500	9/12/1955	10/26/2009	635	893
Illinois River near Viney Grove, AR	07194760	9/6/1978	7/19/2007	80.7	1051
Illinois River at Savoy, AR	07194800	9/11/1968	8/25/2009	167	1019
Osage Creek near Elm Springs, AR	07195000	9/10/1951	8/25/2009	130	1052
Illinois River at Hwy. 16 near Siloam Springs AR	07195400	9/8/1978	9/20/1994	509	1170
Illinois River South of Siloam Springs, AR	07195430	10/3/1972	8/25/2009	575	909
Flint Creek at Springtown, AR	07195800	10/15/1975	7/1/1996	14.2	1173
Flint Creek near West Siloam Springs, OK	07195855	7/11/1979	8/28/1996	59.8	954
Sager Creek near West Siloam Springs, OK	07195865	5/24/1991	10/21/2009	18.9	960
Flint Creek near Kansas, OK	07196000	9/7/1955	10/26/2009	110	855
Peacheater Creek at Christie, OK	07196973	8/6/1991	5/16/1995	25.0	802
Caney Creek near Barber, OK	07197360	8/25/1997	10/27/2009	89.6	638
Illinois River at Chewey, OK	07196090	7/16/1996	10/27/2009	825	801
Illinois River near Gore, OK	07198000	4/12/1940	8/16/1995	1626	468

4.1.2.7 Climate Data

4.1.2.7.1 Precipitation Data

For hydrology calibration of the IRW, all watershed models require precipitation timeseries that are complete records (i.e., no missing data) at a daily or shorter timestep, depending on the selected model, and with adequate spatial coverage and density across the model domain. Precipitation is the critical forcing function for all watershed models as it drives the hydrologic cycle and provides the foundation for transport mechanisms, both flow and sediment, that move pollutants from the land to the waterbody where their impacts are imposed.

For this study, long-term precipitation data have been obtained from the following primary sources:

a. Prior modeling efforts with BASINS/HSPF and SWAT
b. Online databases (e.g., NOAA, USGS) accessed through the BASINS download data capability
c. OK Mesonet data network (provided by ODEQ)
d. Daily NEXRAD data (provided for AR by Drs Matlock and Saraswat at the University of Arkansas (Personal communication, 1 January 2011)
e. BASINS data extended through 12/31/09 (from an ongoing BASINS data project)

The last two precipitation data items (listed above) were obtained since the publication of the Draft Data Report in August 2010. Figure 2.1 shows the precipitation stations used in the IRW modeling effort. These stations are a subset of all the available stations, following a screening of the data to ensure recent and complete records from about 1980 through 2009. This time period provides a 30-year database to support longterm model runs for evaluation of watershed scenarios over a wide range of meteorologic conditions.

In addition to the actual precipitation gage stations, Figure 2.1 shows the ‘pseudo’ stations for the NEXRAD data (discussed below) for the AR portion of the watershed, and a Thiessen polygon analysis for the OK side of the watershed based on the locations of the NWS and OK Mesonet station locations. Thus, a hybrid approach is used, i.e. Thiessen analysis of gage stations on the OK side, and NEXRAD data on the AR side, to make use of the best available precipitation data on both sides of the watershed. Both of these approaches are further discussed below.

The Data Report identified an area of relatively sparse coverage on the AR side of the watershed, about the center of the area where the Illinois River bends toward the west (see Figure 2.1). The study was fortunate to obtain daily precipitation data from Drs Matlock and Saraswat at the University of Arkansas for 28 ‘pseudo’ gage sites (shown as the yellow circles in Figure 2.1), located at the approximate centroid of the HUC12 subwatersheds. This daily data set was developed as a combination of three NWS stations (Bentonville, Fayetteville, and Gravette) for the period 1981-93, and NWS NEXRAD (Next Generation Weather Radar) data for the period 1994-2008.

The station data for the early period (1981-93) were adjusted to the subwatershed centroids using an inverse distance weighting method developed by Zhang and Srinivasan (2009). The extension of these data through 2008 was derived from the NEXRAD Stage III data for 82 4x4 km grid cells within the IRW. In the words of Dr. Saraswat … “The data required several levels of post processing including unzipping, untarring, and transformation from the NEXRAD hydrological rainfall analysis project (HRAP) grid to a geographical coordinate system... All NEXRAD grid points falling within a subwatershed were aggregated; an average value calculated; and assigned to pseudo weather stations at the centroid of the … subwatersheds." (Saraswat, 2010, pg. 18). These data help to fill in the sparse coverage on the AR portion of the IRW; however, due to the manner in which NWS observed data was processed and then combined with NEXRAD data to cover the 1981-2008 period for the 'pseudo' stations, further analysis and evaluation of these data sets was needed as part of the model setup and calibration efforts.

It is critical that the precipitation data demonstrate consistency across the entire IRW in order to produce a scientifically sound hydrologic model. Initial calibration runs demonstrated selected storms with extreme precipitation and little or no response at downstream flow gages, mostly in the AR portion of the watershed which received NEXRAD rainfall data. We referred to these as 'phantom' events since there was no evidence that such extreme rainfall events even occurred. Further analysis identified 10-15 events with rainfall totals at some of the NEXRAD 'pseudo' stations with extreme daily amounts in the range of 10 to 22 inches in a single day. Analysis of the NWS and OK Mesonet stations showed no single day rainfall greater than 8 inches for the entire record from1981 to 2009. Consequently, for these selected events we adjusted the rainfall for the outlier site based on rainfall amounts at neighboring sites. This does raise questions regarding the accuracy of the NEXRAD data for other non-extreme events.

On the OK side of the IRW, four Mesonet stations are combined with up to seven NWS stations, (denoted as BASINS in Figure 2.1, since they are available by download) to provide a reasonable coverage of the watershed within OK. An initial Thiessen analysis is shown in Figure 2.1 (green lines) for the OK side. A Thiessen analysis is a standard hydrologic technique to define the watershed area that will receive rainfall recorded at a specific gage; it involves constructing polygons around each gage using perpendicular bisecting lines drawn at the midpoint of connecting lines between each gage. In other words, the first step is to draw lines connecting the gages, then at the midpoint draw a perpendicular line, then erase the connecting lines; the result is a polygon around each gage. In Figure 4.5, there are nine gages for which the Thiessen analysis produced nine polygons;in the final model, this was reduced to seven polygons, as the Rose Tower gage was eliminated, and the Tahlequah and Webber Falls/Tenkiller polygons were combined into two polygons.

Table 4.7 tabulates all the available precipitation stations, and identifies the Mesonet sites and the specific stations used by Donigian et al (2009) in a prior HSPF/AQUATOX study. In addition to providing detailed 5-minute data, the Mesonet stations by their locations appear to fill in some areas with otherwise sparse gage coverage in the southern and western portions of the IRW. The Mesonet stations also provide extensive meteorologic data, discussed below.

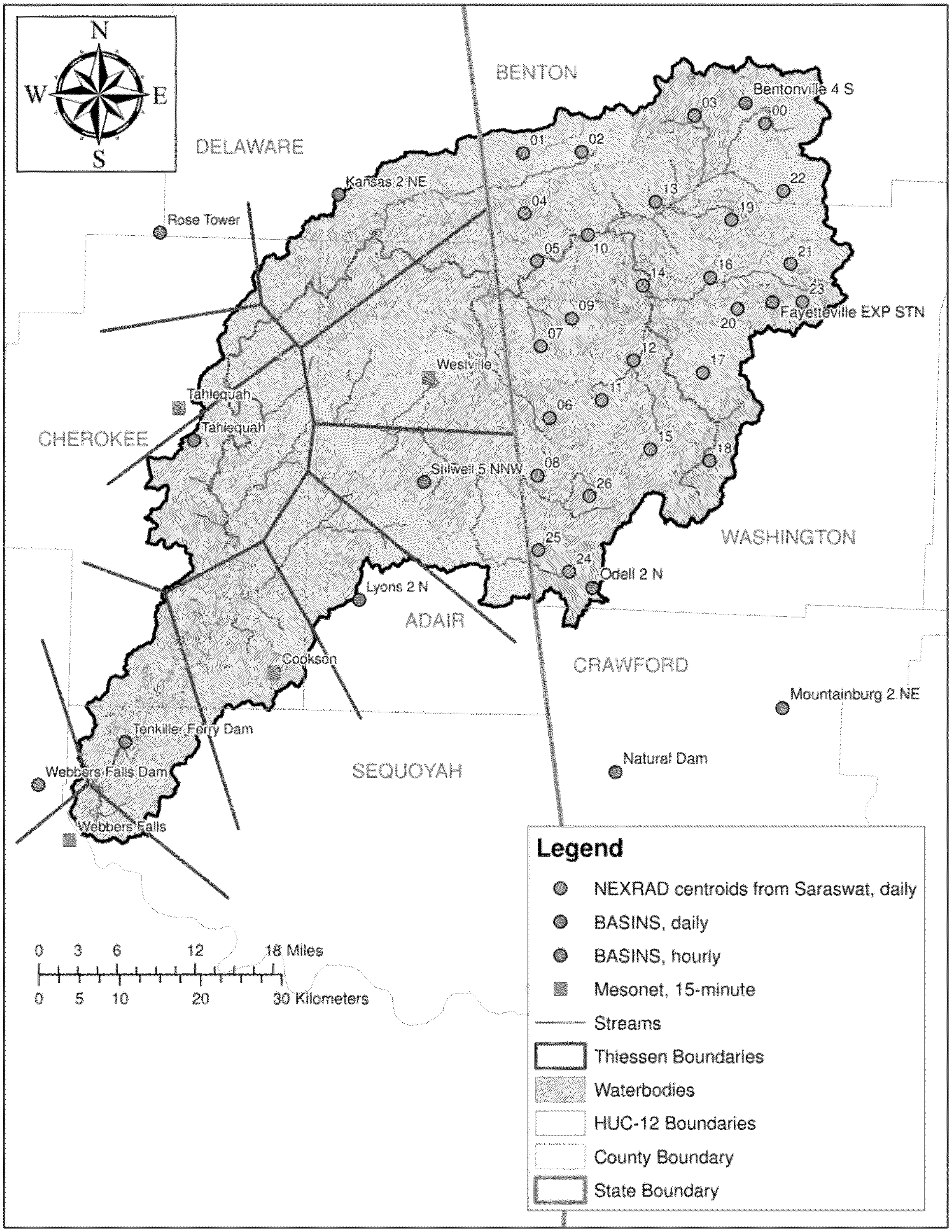


Figure 4.5 Precipitation Stations Selected for Use in the IRW Model

Table 4.7 Precipitation Stations in/near the Illinois River Watershed

Site Name	Site Number	Source	Start	End	Av Annual Precip (in)
Bentonville 4S	AR030586	BASINS daily	12/31/1947	2/28/2007	46.79
Cookson	31	Mesonet 5-min	1/1/1994	5/26/2010	50.50
Fayetteville Exp Sta*	AR032444	BASINS hourly	4/1/1966	3/31/2006	46.17
Fayetteville Exp Sta*	AR032444	BASINS daily	12/14/1926	8/31/2003	46.17
Mountainburg 2NE	AR035018	BASINS daily	8/31/1985	12/31/2009	50.61
Natural Dam	AR035160	BASINS daily	12/31/1962	12/31/2009	49.39
Odell 2 N*	AR035354	BASINS daily	12/31/1947	12/31/2009	51.56
Kansas 2 NE*	OK344672	BASINS daily	3/31/1959	12/31/2009	48.23
Lyons 2 N*	OK345437	BASINS daily	12/31/1947	9/30/2003	47.75
Rose Tower*	OK347739	BASINS hourly	1/1/1974	12/31/2003	46.79
Stilwell 5 NNW*	OK348506	BASINS daily	9/30/1948	4/30/2003	49.11
Tahlequah*	OK348677	BASINS daily	12/31/1947	12/31/2006	47.64
Tahlequah	92	Mesonet 5-min	1/1/1994	5/26/2010	47.50
Tenkiller Ferry Dam*	OK348769	BASINS hourly	4/1/1949	1/31/1999	46.33
Webbers Falls	103, 132	Mesonet 5-min	1/1/1994	5/26/2010	46.50
Westville	104	Mesonet 5-min	1/1/1994	5/26/2010	48.90

*This station was previously used in the HSPF/AQUATOX study by Donigian et al (2009).

Based on the previous HSPF and SWAT modeling efforts, and the precipitation stations identified in **Table 4.7** and Figure 4.5,, the coverage of daily stations appears sufficient for coverage of the IRW, especially with the addition of the Mesonet stations on the Oklahoma side and the NEXRAD data for the Arkansas side.

To simulate individual storm events, HSPF requires hourly data, and the conventional practice is to use nearby hourly stations to disaggregate daily precipitation values to hourly increments. The BASINS procedures for performing this disaggregation involve identifying up to 30 nearby stations, selecting the hourly station based on both geographic distance (proximity) and similarity of daily vales, and then using the hourly distribution at that station to transform the daily station value into 24 hourly values. A tolerance threshold is used to only select stations whose daily total is within a certain percentage of the daily value for the station being disaggregated. Typical tolerance values are in the range of 30% to 90%, depending on the availability of nearby alternate gages.

For the IRW, there are seven hourly stations, which include four Mesonet and three BASINS stations derived from NWS data. The combined Mesonet and BASINS hourly sites provide a good distribution for the OK side of the watershed, whereas hourly distributions for the AR side were derived from the Fayetteville, AR and from the Westville Mesonet site in OK.

4.1.2.7.1 Evaporation and Other Meteorological Data

Watershed models require evaporation data as a companion to precipitation to drive the water balance calculations inherent in the hydrologic algorithms contained in these types of models. In addition, other meteorologic time series are also often required in temperate climates where snow accumulation and melt are a significant component of the hydrologic cycle and water balance. These same time series, such as air temperature, solar radiation, dewpoint temperature, wind, and cloud cover, are often required if soil and/or water temperatures are simulated. Water temperature is subsequently used to adjust rate coefficients in most water quality processes, and other time series are used in selected calculations, like solar radiation affecting algal growth.

Both HSPF and SWAT have similar weather data requirements (with some slight differences), so the availability of weather data is expected to be adequate for model application, considering both models have been previously applied to the IRW.

HSPF generally uses measured pan evaporation to derive an estimate of lake evaporation, which is considered equal to the potential evapotranspiration (PET) required by model algorithms, i.e., PET = (pan evap) X (pan coefficient). The actual simulated evapotranspiration is computed by the program based on the model algorithms that calculate dynamic soil moisture conditions, ET parameters, and the input PET data. Where pan evaporation is not available, potential evapotranspiration (PET) can be computed from minimum and maximum daily air temperatures using the Hamon formula (Hamon, 1961). This method was used to compute the PET data included in the BASINS database of available meteorologic time series. The Hamon method generates daily potential evapotranspiration (inches) using air temperature (F or C), a monthly variable coefficient, the number of daylight hours (computed from latitude), and absolute humidity (computed from air temperature).

Recently, BASINS has been enhanced to also allow computation of PET according to the Penman-Monteith method, which involves a more detailed computation requiring air temperature, solar radiation, relative humidity, and wind speed, along with other coefficients. The method incorporated into BASINS was based on procedures included in the SWAT model. As part of the model setup effort, PET estimates from both the Hamon and Penman-Monteith methods were compared, along with available pan evaporation data, and the Hamon method was selected as most representative of IRW. Initial calibration runs confirmed that the Hamon values were more consistent with the expected PET for the IRW.

The primary source of evapotranspiration and the other meteorologic data was the BASINS database of thousands of stations across the US; the download capability within BASINS allows users to identify their selected watersheds and then access all the data available, including meteorologic data. Figure 4.5 shows the available meteorologic stations in and near the IRW available through BASINS; it also shows the nearest OK Mesonet stations. The OK Mesonet is an automated network of hundreds of remote meteorologic stations across OK instrumented to monitor and measure soil and meteorologic conditions. As shown in Figure 4.5, there are four Mesonet stations within or near the IRW.

Table 4.8 lists the meteorologic stations found through BASINS along with the Mesonet sites. The nearest pan evaporation station to the IRW is the Blue Mountain Dam NWS site approximately 30 miles southeast of the watershed. This site was used as the only evaporation data station for the HSPF/AQUATOX study; since PET generally demonstrates little spatial variability in this climate region, compared to rainfall variability, the distance was not considered excessive. **Table 4.8** shows 14 sites with BASINS computed evapotranspiration data providing sufficient coverage for the IRW. Also, the stations available for the remaining weather data, combined with the Mesonet sites, appear to provide a similar level of coverage. As noted above, the various estimates of PET – Blue Mountain Dam pan data, Hamon method, Penman-Monteith method – were compared and the Hamon method was determined the most representative method to use for this study. In addition, Thiessen analyses, analogous to what was discussed above for the precipitation stations, were performed to identify the watershed areas for which each meteorological time series were applied. Since PET and air temperature are the more critical of the meteorologic forcing data sets, and more data sites are available, we have a denser network for PET and air temperature than for wind, solar radiation, dewpoint temperature, or cloud cover. The periods of available historic data for these meteorologic data, starting mostly about 1995, is consistent with our expected calibration and validation periods (discussed in Section 4).

Table 4.8 Meteorological Stations in/near the Illinois River Watershed

Site Name	Site Number	Source	Data Type	Start	End
Bentonville (AWOS)	AR723444	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1995	12/31/2009
Bentonville 4S	AR030586	BASINS	ATEM, PET	1/1/1948	2/28/2007
Blue Mountain Dam*1		Previous study	ATEM, PET	1/1/1984	9/30/2004
Cookson	31	Mesonet	ATEM, BP, SOLR, WIND	1/1/1994	present
Fayetteville Exp Sta	AR032444	BASINS	ATEM, PET	8/26/1921	8/31/2003
Fayetteville FAA Airport	AR032443	BASINS	WIND, SOLR, DEWP, CLOUD	12/31/1994	12/31/2009
Kansas 2 NE	OK344672	BASINS	ATEM, PET	4/1/1959	1/1/2010
Muskogee	OK346130	BASINS	ATEM, PET	1/1/1948	12/31/2009
Rogers	AR723449	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1995	12/31/2009
Siloam Springs (AWOS)	AR723443	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1995	12/31/2009
Stilwell 5 NNW	OK348506	BASINS	ATEM, PET	1/1/1960	4/30/2003
Tahlequah	OK348677	BASINS	ATEM, PET	1/1/1948	12/31/2006
Tahlequah	92	Mesonet	ATEM, BP, SOLR, WIND	1/1/1994	present
Webbers Falls	103, 132	Mesonet	ATEM, BP, SOLR, WIND	1/1/1994	present
Webbers Falls Dam	OK349450	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1970	12/31/2009

4.1.2.8 ***Point Sources***

Data on point sources discharges have been compiled from a number of different sources of information, including data provided by EPA, State representatives, and the dischargers. Prior modeling efforts focused on the major dischargers, and ignored the contributions from the numerous minor and smaller ones. A similar approach is followed in this effort as the detailed time series data needed is not available for the minor dischargers.

Point source loads have been developed for 13 primary facilities (**Table 4.9**) that discharge to the Illinois River and its tributaries. The primary basis for developing the point source loads were (1) internal monitoring data provided by individual facilities (Springdale, Fayetteville, Lincoln, Rogers, Siloam Springs, Tahlequah, Stilwell) and (2) Discharge Monitoring Report

(DMR) data provided by Oklahoma DEQ (Andrew Fang) and Arkansas DEQ. Bicknell and Donigian (2012) document the data, procedures, and assumptions that were used to develop the loads.

Table 4.9 Point Sources in Illinois River Watershed

NPDES #	Facility	Discharge Location (Tributary)	Typical Flow (MGD)
AR0022098	Prairie Grove, City of	Muddy Fork	0.3
AR0020010	Fayetteville - Paul Noland WWTP	Mud Ck	4.5
AR0050288	Fayetteville - Westside WWTP	Goose Ck	5.8
AR0033910	USDA FS - Lake Wedington Rec. Area	Tributary to Illinois R	0.0013
AR0035246	Lincoln, City of	Bush Ck/Baron Fork	0.45
AR0022063	Springdale WWTP, City of	Spring Ck/Osage Ck	12
AR0043397	Rogers, City of	Osage Ck	6.5
AR0020184	Gentry, City of	SWEPCO Res/L Flint Ck	0.45
AR0020273	Siloam Springs, City of	Sager Ck/Flint Ck	3
AR0037842	SWEPCO Flint Ck Power Plant	SWEPCO Res/Flint Ck	5/400 *
OK0026964	Tahlequah Public Works Authority	Tahlequah Ck	2.7
OK0028126	Westville Utility Authority	Shell Branch/Baron Fork	0.2
OK0030341	Stilwell Area Development Authority	Caney Ck	0.85

* - Once-through cooling water outflow (400 MGD) and wastewater outflow (5 MGD)

The quantities that were generated are listed below. They include flow, heat, and the water quality-related constituents that are being modeled by HSPF.

Quantity	Units
Flow	MG (input as ac-ft)
Heat	BTU
TSS	lbs (input as tons)
DO	lbs O
NO3/NO2	lbs N
NH3/NH4	lbs N
Organic N	lbs N
PO4	lbs P
Organic P	lbs P
$CBOD_u$	lbs O
Organic C	lbs C

The data availability and frequency are summarized in **Table 4.10**, and the average daily values (in units of lbs/day) of all quantities for the full 1990-2009 period are shown in **Table 4.11** ; spreadsheets of the daily and monthly values were provided to EPA and stakeholders November 2012. Total TN, TP, and $CBOD_u$ loads for 2009 are shown in **Table 4.12**. Although these tables show summaries of average daily and annual loads, the model actually receives the daily loads as a timeseries for the entire period of 1990-2009; these values are included with the daily load spreadsheet provided to EPA and stakeholders.

Table 4.10 Data Availability and Measurement Frequency of Point Sources

NPDES #	Facility	Monthly DMR Data	Weekly/Daily Data
AR0022098	Prairie Grove, City of	1990/1 - 2009/12	n/a
AR0020010	Fayetteville - Paul Noland WWTP	1990/1 - 2008/6	1990/1 - 2008/6
AR0050288	Fayetteville - Westside WWTP	n/a	2008/6 - 2009/12
AR0033910	USDA FS - Lake Wedington Rec. Area	1990/1 - 2009/12	n/a
AR0035246	Lincoln, City of	1990/1 - 2009/12	2001/1 - 2009/12
AR0022063	Springdale WWTP, City of	1990/1 - 2009/12	1991/10 - 2009/12
AR0043397	Rogers, City of	1990/1 - 2009/12	1990/1 - 2009/12
AR0020184	Gentry, City of	1990/1 - 2009/12	n/a
AR0020273	Siloam Springs, City of	1990/1 - 2009/12	2002 - 2009/12
AR0037842	SWEPCO Flint Ck Power Plant	1990/1 - 2009/12	n/a
OK0026964	Tahlequah Public Works Authority	1990/1 - 2009/12	2001/1 - 2009/12
OK0028126	Westville Utility Authority	1990/1 - 2009/12	n/a
OK0030341	Stilwell Area Development Authority	1990/1 - 2009/12	2006/1 - 2009/12

Table 4.11 Average Daily Point Source Loads for 1990-2009

Facility	Flow mgd	Heat btu/day	DO lb/day	TSS lb/day	$CBOD_5$ lb/day	$CBOD_U$ lb/day	Ref Org C lb/day	TP lb/day	PO4 lb/day	Org P lb/day	TN lb/day	NH3 lb/day	NO3 lb/day	OrgN lb/day
Prairie Grove	0.27	7.5E+7	19	19	9.0	25.5	2.4	10	7.7	2.6	17.4	1.9	11	4.4
Fayetteville Noland	3.9	1.1E+9	311	82	65	184	17	14	10	3.5	242	12	164	65
Fayetteville Westside (2008/6-2009)	5.8	1.7E+9	441	43	93	265	71	21	16	5.3	349	7.6	244	98
USDA-Lake Wedington	.0013	3.7E+5	0.095	0.063	0.050	0.14	0.014	.0046	.0035	.0012	.0864	0.011	0.054	0.022
Lincoln	0.46	1.1E+8	34	15	24	68	6.4	6.0	4.5	1.5	24.3	3.2	13	7.7
Springdale	11	3.2E+9	872	352	199	566	53	304	270	54	558	41	369	149
Rogers	5.5	1.5E+9	450	218	123	348	33	67	17	50	262	10	202	54
Gentry	0.47	1.3E+8	35	44	41	118	11	15	11	3.7	32	4	20	7.9
Siloam Springs	2.7	8.1E+8	187	203	73	207	19	76	57	19	290	13	231	46
SWEPCO	359	5.7E+11	2.7E+4	575	33*	94*	8.8*	15*	11*	3.7*	32*	4*	20*	7.9*
Tahlequah	2.7	7.7E+8	176	53	85	241	23	21	16	5.3	176	20	111	45
Westville	0.18	4.9E+7	13	38	18	50	4.7	3.1	2.3	0.8	13.2	2.8	7.5	3.0
Stilwell	0.71	2.0E+8	44	50	58	164	15	6.0	4.5	1.5	52.5	11.3	29	12

* SWEPCO nutrient loads based on Gentry data

Table 4.12 Annual Loads (lbs/year) of TP, TN, and CBODu for 2009

NPDES #	Facility	TP	TN	$CBOD_u$

AR0022098	Prairie Grove	3,400	7,100	5,310
AR0020010	Fayetteville - Noland (2007)	3,980	125,000	126,000
AR0050288	Fayetteville - Westside	7,910	139,000	106,000
AR0033910	USDA FS - Lake Wedington	4.54	92.5	192
AR0035246	Lincoln	1,540	11,500	6,020
AR0022063	Springdale	16,900	248,000	169,000
AR0043397	Rogers	5,380	192,000	75,400
AR0020184	Gentry	4,920	13,600	19,000
AR0020273	Siloam Springs	12,600	63,000	42,000
AR0037842	SWEPCO	*4,920	*13,600	*19,000
OK0026964	Tahlequah	3,910	75,000	55,400
OK0028126	Westville	489	6,910	7,910
OK0030341	Stilwell	1,920	26,100	57,500

* SWEPCO loads based on Gentry data

The primary data available for many of the facilities was derived from DMR sources, and consists of monthly averages of flow and the following constituents: $CBOD_5$, TSS, DO, NH3, and TP. Eight of the facilities provided daily/weekly data for selected time periods, and those data were used when available. While it is likely that most flow rates are based on frequent (daily) measurements, the other constituent monthly averages were apparently obtained from one to two measurements per month. For five of the facilities, this type of monthly data are the only data available (facilities with "n/a" in **Table 4.10**); four of the facilities (Fayetteville-Noland, Fayetteville-Westside, Rogers, and Springdale) have essentially a complete period (1990/1/1 - 2009/12/31) of daily/weekly data; and the remaining four facilities (Lincoln, Siloam Springs, Tahlequah, and Stilwell) utilize monthly data for the earlier years, and are supplemented by more frequent measurements (typically weekly) for the later years. In general, where monthly and weekly (or daily) data overlapped in time, the more frequent measurements were used to develop the final loads.

4.1.3 HSPF Model Calibration

Calibration of the IRW model was an iterative process of making parameter changes, running the model and producing comparisons of simulated and observed values, and interpreting the results. This process occurs first for the hydrology portions of the model, followed by the water quality portions. The procedures have been well established over the past 30 years as described in the HSPF Application Guide (Donigian et al., 1984) and summarized by Donigian (2002). This section on model calibration is a summary of the HSPF Model application and calibration to the IRW for TMDL development; the HSPF calibration to the IRW watershed is fully described in the original model report (MBI et al., 2015).

4.1.3.1 ***Hydrology Calibration and Validation***

Calibration of HSPF to represent the hydrology of the IRW is an iterative trial-and-error process. Simulated results are compared with recorded data for the entire calibration period, including both wet and dry conditions, to see how well the simulation represents the hydrologic response observed under a range of climatic conditions. By iteratively adjusting specific calibration parameter values, within accepted and physically-based ranges, the simulation results are changed until an acceptable comparison of simulation and recorded data is achieved.

The standard HSPF hydrologic calibration is divided into four phases: (1) Establish an annual water balance; (2) Adjust low flow/high flow distribution; (3) Adjust stormflow/hydrograph shape; and (4) Make seasonal adjustments. The same model-data comparisons are performed for both the calibration and validation periods. In addition to these comparisons, the water balance components (input and simulated) are reviewed and evaluated. Although observed values are not available for each of the water balance components listed above, the average annual values must be consistent with expected values for the region, as impacted by the individual land use categories. This is a separate consistency, or reality, check with data independent of the modeling (except for precipitation) to ensure that land use categories and the overall water balance reflect local conditions.

The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. (1984), the HSPF hydrologic calibration expert system (HSPEXP) (Lumb, McCammon, and Kittle, 1994), and the IRW HSPF Model Application Report (MBI et al., 2015).

Complete flow calibration and validation results are provided in the Final IRW Report, Appendix A (MBI et al., 2015). These results consist of a summary statistics table for all sites, and annual volumes and percent error table for each site, followed by flow duration and daily time series plots (arithmetic and log) for each site. Appendix A first presents the results for calibration and then validation.

Table 4.13 shows the calibration and validation summary statistics for all sites, while **Table 4.14** and **Table 4.15** show the annual volume comparisons at the Stateline (Illinois River South of Siloam Springs – Reach 630) and at Tahlequah (Illinois River near Tahlequah OK – Reach 870), respectively.

Review of these results, compared to criteria listed in the Final IRW Model report, indicate the following:

a. Annual flow comparison shows a Very Good or better calibration, with all the calibration volume errors less than 10%. The validation volume errors are higher, as is expected, with all the errors within 14%, except for Caney Creek which is an outlier at 40% error.
b. The Monthly R2 and NSE (Nash-Sutcliff Efficiency) measures are consistently comparable, and are in the range of 0.65 to 0.91 (average of 0.80), corresponding to a Fair to Very Good range. The lowest values are primarily at one or two sites, which are commonly the smallest calibration sites (e.g., Sager Creek and Baron Fork at Dutch Mills). The smaller the site, the more it is impacted by errors in representative rainfall; more discussion is provided below.
c. The Calibration Daily R2 values are consistently lower, as is expected, with an average value of 0.63, and a range of 0.50 to 0.78. This corresponds to a Poor/Fair to Good rating.

d. The Annual Flow Volumes in Table 4.14(for Stateline) and Table 4.15 (for Tahlequah), and those in Appendix A, show a wide range in year-to-year differences, with the year 2006 especially problematic, usually over-simulated, for a number of the sites. Year 2006 was the second year of an extreme drought which may have contributed to the issues.

e. The flow-duration curves are one of the primary metrics for judging acceptance of model results, as they demonstrate the behavior of the model throughout the entire range of flows on the contributing watershed. Figure 4.6 and Figure 4.7 show the flow duration curves for the Illinois River at the Stateline and Tahlequah, for both calibration and validation. It is clear that the calibration (Figure 4.6) does a very good job of reproducing the observed flow duration curve at both sites, and a similar level of agreement is shown for the validation curves (Figure 4.7). In fact, for the Tahlequah site, the validation curve might be considered slightly better than the calibration curve, as the curves are almost indistinguishable for all flows above about 200 cfs.

In summary, the model results show a Fair to Good overall calibration and validation, and in some cases (i.e., sites) a Very Good simulation, confirming that the overall model provides a sound basis for subsequent water quality simulations.

Table 4.13 Calibration (top) and Validation (bottom) Summary Statistics

Reach	Calibration Statistics	Annual Flow (in)			Daily		Monthly		Daily Peaks % Diff	NSE	
	Name	Sim	Obs	% Vol error	R	R^2	R	R^2		Daily	Monthly
150	Illinois River at Savoy, AR	14.59	13.77	5.97	0.81	0.65	0.91	0.83	-8.96	0.63	0.83
316	Osage Creek near Elm Springs, AR	18.64	17.07	9.18	0.77	0.59	0.88	0.77	0.72	0.48	0.74
516	Sager Creek near West Siloam Springs, OK	18.13	18.03	0.56	0.71	0.50	0.81	0.65	-12.84	0.40	0.65
523	Flint Creek near Kansas, OK	12.75	12.28	3.78	0.79	0.62	0.89	0.80	3.45	0.57	0.79
630	Illinois River South of Siloam Springs, AR	14.13	14.07	0.43	0.83	0.69	0.91	0.83	-8.44	0.67	0.82
640	Illinois River near Watts, OK	13.76	13.60	1.18	0.81	0.66	0.92	0.85	-3.48	0.63	0.84
706	Baron Fork at Dutch Mills, AR	14.81	15.10	-1.89	0.75	0.57	0.84	0.70	-8.46	0.49	0.69
746	Baron Fork at Eldon, OK	14.10	13.69	3.01	0.88	0.78	0.95	0.91	-6.91	0.78	0.91
870	Illinois River near Tahlequah, OK	13.57	13.74	-1.27	0.77	0.60	0.95	0.90	-11.77	0.58	0.88
912	Caney Creek near Barber, OK	14.20	13.18	7.70	0.79	0.62	0.90	0.81	4.44	0.57	0.80
Mean Values		14.87	14.45	2.87	0.79	0.63	0.90	0.80	-5.22	0.58	0.80

Reach	Validation Statistics		Annual Flow (in)			Daily		Monthly		Daily Peaks % Diff	NSE	
	Name	record starts	Sim	Obs	% Vol error	R	R^2	R	R^2		Daily	Monthly
150	Illinois River at Savoy, AR	1996	13.64	14.40	-5.29	0.67	0.45	0.86	0.74	-22.63	0.29	0.73
316	Osage Creek near Elm Springs, AR	1996	17.85	15.86	12.55	0.71	0.50	0.89	0.79	-3.61	0.14	0.69
516	Sager Creek near West Siloam Springs, OK	1997	19.63	17.22	13.99	0.48	0.23	0.61	0.37	-34.63	0.00	0.31
523	Flint Creek near Kansas, OK	1993	16.75	15.34	9.18	0.67	0.44	0.84	0.71	-8.85	0.29	0.69
630	Illinois River South of Siloam Springs, AR	1996	13.43	14.95	-10.19	0.77	0.59	0.91	0.82	-16.46	0.57	0.81
640	Illinois River near Watts, OK	1992	16.79	16.30	2.97	0.78	0.62	0.90	0.81	18.45	0.46	0.80
706	Baron Fork at Dutch Mills, AR	1992	18.65	18.48	0.90	0.42	0.18	0.73	0.53	-0.71	-0.29	0.47
746	Baron Fork at Eldon, OK	1992	18.13	18.43	-1.65	0.85	0.73	0.93	0.87	-6.47	0.72	0.87
870	Illinois River near Tahlequah, OK	1992	16.40	16.20	1.24	0.75	0.57	0.91	0.84	-1.99	0.51	0.84
912	Caney Creek near Barber, OK	1998	20.52	14.71	39.52	0.83	0.69	0.93	0.87	59.18	0.32	0.74
Mean Values			17.18	16.19	6.10	0.69	0.50	0.85	0.73	-1.77	0.30	0.69

Table 4.14 Annual Flow Volumes in Inches for the Illinois River South of Siloam Springs (Reach 630) for the Calibration (top) and Validation (bottom) Periods

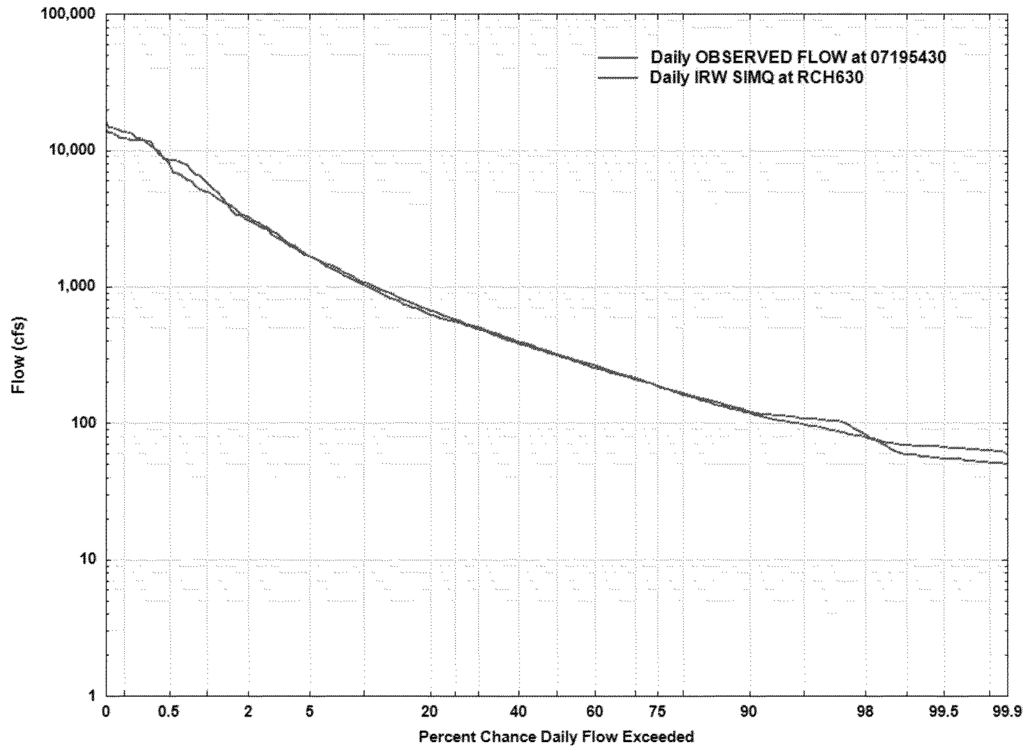
Year	Precipitation (in)	Simulated Flow (in)	Observed Flow (in)	Residual (in)	Percent Error
2001	47.60	15.46	14.23	1.22	8.60%
2002	41.70	14.85	14.24	0.61	4.30%
2003	35.70	8.70	7.32	1.37	18.73%
2004	45.87	16.65	15.13	1.52	10.06%
2005	30.25	10.26	10.42	-0.16	-1.50%
2006	46.26	11.23	6.92	4.31	62.36%
2007	34.04	9.83	10.42	-0.58	-5.57%
2008	53.43	20.79	26.09	-5.30	-20.31%
2009	54.27	19.36	21.83	-2.47	-11.32%
Mean	43.24	14.13	14.07	0.06	0.42%

Year	Precipitation (in)	Simulated Flow (in)	Observed Flow (in)	Residual (in)	Percent Error
1996	28.60	6.08	8.38	-2.31	-27.45%
1997	44.77	15.84	18.64	-2.80	-15.02%
1998	43.87	16.55	15.52	1.04	6.64%
1999	51.59	18.62	18.51	0.11	0.59%
2000	36.05	10.05	13.71	-3.66	-26.70%
Mean	40.98	13.43	14.95	-1.52	-10.19%

Table 4.15 Annual Flow Volumes in Inches for the Illinois River near Tahlequah (Reach 870) for the Calibration (top) and Validation (bottom) Periods

Year	Precipitation (in)	Simulated Flow (in)	Observed Flow (in)	Residual (in)	Percent Error
2001	46.01	13.42	14.77	-1.35	-9.17%
2002	41.06	13.01	12.16	0.84	6.94%
2003	36.20	7.91	6.83	1.07	15.72%
2004	48.19	16.86	16.59	0.27	1.63%
2005	31.14	9.69	10.20	-0.50	-4.93%
2006	45.11	9.44	6.12	3.32	54.15%
2007	36.57	10.01	10.52	-0.51	-4.85%
2008	56.93	22.93	26.36	-3.43	-13.02%
2009	53.81	18.84	20.11	-1.27	-6.33%
Mean	43.89	13.57	13.74	-0.17	-1.25%

Year	Precipitation (in)	Simulated Flow (in)	Observed Flow (in)	Residual (in)	Percent Error
1992	53.95	17.35	17.30	0.05	0.29%
1993	60.35	27.36	25.03	2.32	9.31%
1994	48.92	17.58	15.32	2.26	14.75%
1995	43.39	16.54	16.05	0.49	3.05%
1996	40.54	11.74	13.44	-1.70	-12.65%
1997	42.74	11.77	11.82	-0.05	-0.42%
1998	44.73	15.71	14.92	0.78	5.29%
1999	43.62	16.01	16.34	-0.33	-2.02%
2000	45.98	13.50	15.53	-2.02	-13.07%
Mean	47.14	16.40	16.19	0.20	1.24%



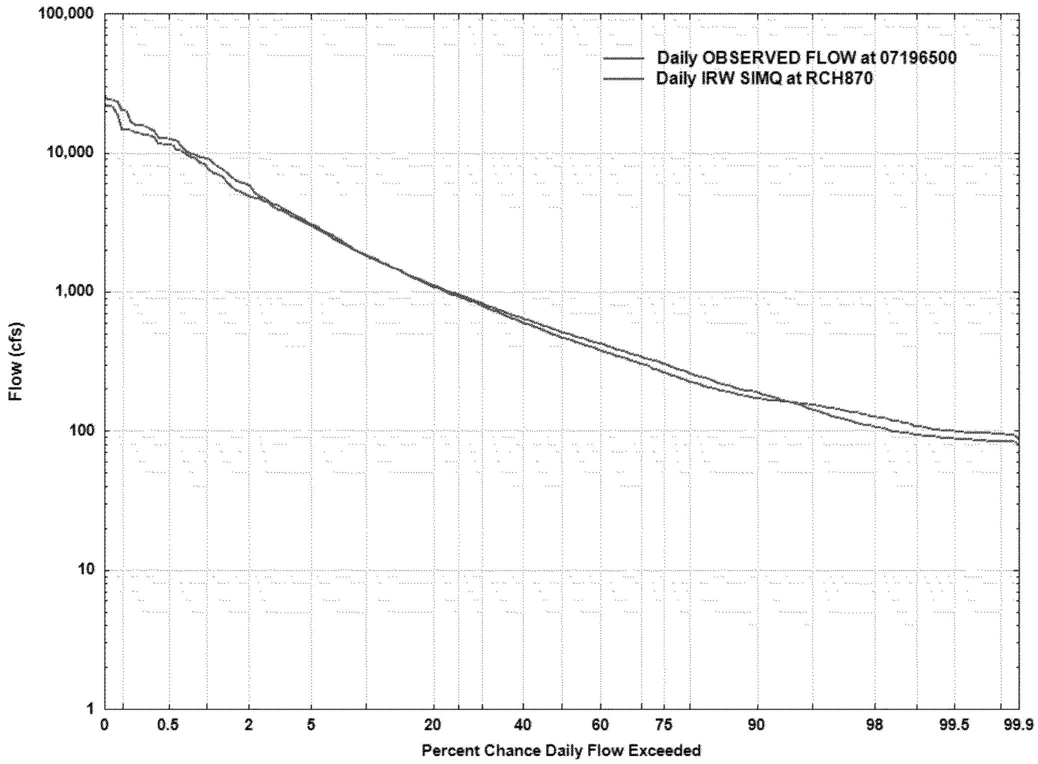
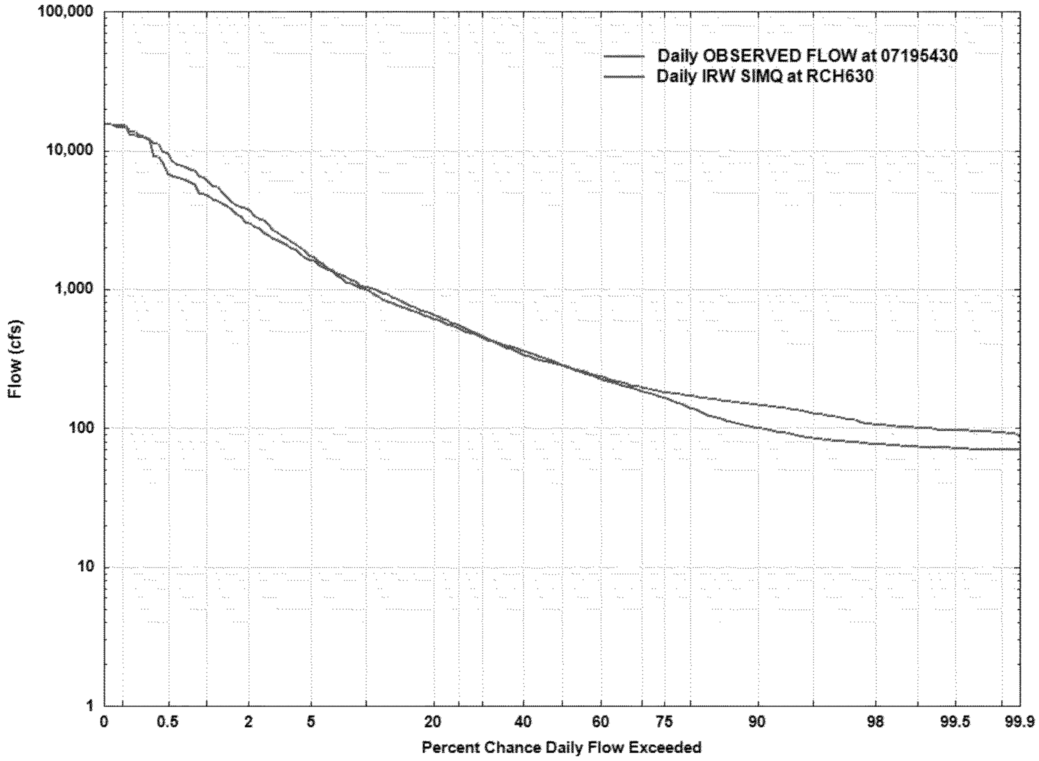


Figure 4.6 Daily Flow Duration Comparisons for the State Line (Reach 630) and Tahlequah (Reach 870) for the Calibration Period



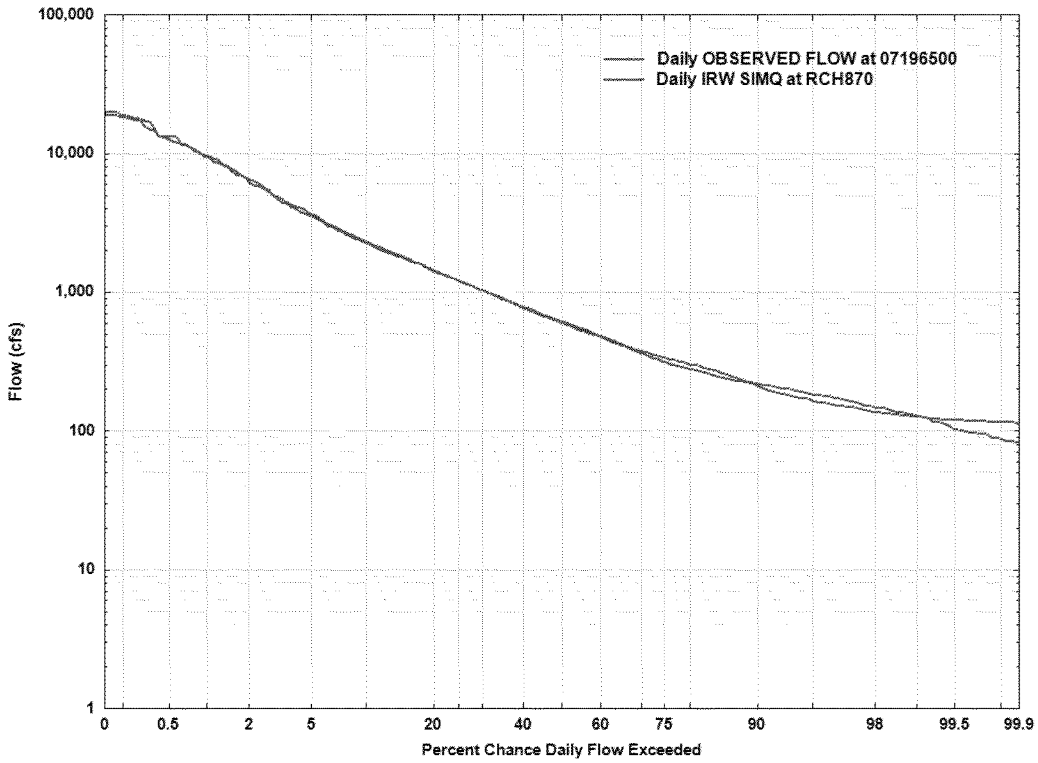


Figure 4.7 Daily Flow Duration Comparisons for the State Line (Reach 630) and Tahlequah (Reach 870) for the Validation Period

4.1.3.2 ***Watershed Quality Calibration***

Water quality calibration is also an iterative process; the model predictions are the integrated result of all the assumptions used in developing the model input and representing the modeled sources and processes. Differences in model predictions and observations require the model user to re-evaluate these assumptions, in terms of both the estimated model input and parameters and consider the accuracy and uncertainty in the observations. At the current time, water quality calibration is more an art than a science, especially for comprehensive simulations of nonpoint, point, and atmospheric sources, and their impacts on instream water quality.

The following steps were performed at each of the calibration stations, following the hydrologic calibration and validation, and after the completion of input development for point source, atmospheric, and other contributions:

A. Estimate all model parameters, including land use specific accumulation and depletion/removal rates, washoff rates, and subsurface concentrations
B. Tabulate, analyze, and compare simulated annual nonpoint loading rates with the expected range of nonpoint loadings from each land use (and each constituent) and adjust loading parameters when necessary
C. Calibrate instream water temperature to observed data
D. Compare simulated and observed instream concentrations at each of the calibration stations, and compare simulated and estimated loads where available
E. Analyze the results of comparisons in steps B, C, and D to determine appropriate instream and/or nonpoint parameter adjustments needed until model performance targets are achieved

The essence of watershed water quality calibration is to obtain acceptable agreement of observed and simulated concentrations (i.e. within defined criteria or targets), while maintaining the instream water quality parameters within physically realistic bounds, and the nonpoint loading rates within the expected ranges from the literature. The nonpoint loading rates, sometimes referred to as 'export coefficients' are highly variable, with value ranges sometimes up to an order of magnitude, depending on local and site conditions of soils, slopes, topography, climate, etc.

4.1.4 Pollutant Loads for Existing Condition

As noted above, water quality calibration begins with calibration of the nonpoint loading rates to available data and expected, or 'target', loading rates which will vary by location within the watershed (i.e., soils, slope, land cover) and land use. Sediment calibration follows analogous procedures in that target sediment loading rates are developed and used to guide the sediment loading rate calibration, as defined in Step B (above). Below we summarize Steps B, C, and D as they apply to the sediment calibration, followed by the water temperature calibration and validation. Complete details are provided in the FInal IRW Report, Appendix B (MBI et al., 2015) which presents the complete sediment calibration results, while Appendix C presents the water temperature calibration and validation results.

During calibration the sediment erosion model parameters are adjusted to produce the final rates within the target range, while producing TSS concentrations, and any available loading data, within the range of the observations. In most case, the only observations will be instream TSS concentrations, so the calibration procedure involves adjustments to both the loading rates and instream sediment transport parameters, until overall agreement is reached. Table

4-7 presents the final sediment loading rates resulting from this iterative calibration effort, by land use category across the top, and by meteorologic segment (yellow highlighted numbers and blue station designations, in the first two columns).

Table 4.16 demonstrates a significant range in sediment loading rates across the IRW even within a single land use category. This is primarily due to both slope and precipitation variations. These ranges are generally consistent with the target rages but occasionally will fall outside the target range. Overall, the rates are consistent with available information on sediment loading and past modeling studies in the Midwest.

Table 4.16 Annual Sediment Loading Rates (tons/acre/year) for the IRW

		PERLND										IMPLND		
	Land Use Code	1	2	3	4	5	6	7	8	9	10	6	7	8
	Land Use Name	Forest	Pasture1 / Litter	Pasture2	Pasture3	Grass/Shrub/ Barren	Developed, Open	Developed, Low	Developed, Med/High	Wetlands	Cropland	Developed, Open	Developed, Low	Developed, Med/High
20	PCP_18	0.118	0.521	0.874	1.022	0.688	0.399	0.428	0.581	0.036	2.118	0.138	0.198	0.310
40	PCP_24	0.070	0.591	0.754	0.731	0.610	0.247	0.283	0.396	0.014	1.351	0.134	0.191	0.294
60	PCP_26	0.119	0.640	0.772	0.854	0.779	0.280	0.329	0.477	0.019	1.669	0.137	0.196	0.304
80	Stillwell 5 NNW	0.075	0.480	0.527	0.431	0.479	0.207	0.259	0.328	0.001	0.927	0.124	0.180	0.279
100	PCP_11	0.120	0.577	0.570	0.659	0.653	0.213	0.251	0.362	0.003	1.895	0.136	0.195	0.297
120	PCP_06	0.007	0.225	0.226	0.264	0.406	0.160	0.186	0.269	0.002	0.582	0.132	0.186	0.283
140	Westville	0.048	0.464	0.457	0.505	0.510	0.167	0.202	0.296	0.001	0.879	0.122	0.176	0.270
160	PCP_12	0.064	0.387	0.384	0.447	0.510	0.154	0.180	0.259	0.001	1.270	0.135	0.194	0.298
180	PCP_17	0.071	0.379	0.381	0.441	0.528	0.196	0.233	0.334	0.004	1.622	0.134	0.193	0.297
200	PCP_09	0.006	0.193	0.198	0.232	0.343	0.142	0.164	0.234	0.002	0.733	0.129	0.185	0.285
220	PCP_07	0.008	0.215	0.220	0.257	0.365	0.150	0.177	0.253	0.001	0.773	0.129	0.185	0.281
240	PCP_21	0.008	0.311	0.317	0.348	0.394	0.167	0.195	0.281	0.001	0.731	0.131	0.188	0.291
260	PCP_16	0.004	0.237	0.237	0.306	0.394	0.130	0.156	0.226	0.002	0.513	0.133	0.191	0.292
280	PCP_14	0.055	0.339	0.389	0.429	0.562	0.190	0.223	0.321	0.005	1.393	0.134	0.195	0.303
300	PCP_05	0.005	0.162	0.169	0.197	0.311	0.115	0.137	0.195	0.001	0.417	0.133	0.191	0.295
320	Cookson	0.063	0.635	0.678	0.553	0.521	0.217	0.261	0.331	0.003	1.487	0.123	0.177	0.279
340	PCP_10	0.010	0.305	0.313	0.359	0.413	0.181	0.212	0.308	0.003	0.929	0.131	0.188	0.288
360	PCP_23	0.052	0.487	0.499	0.549	0.515	0.255	0.287	0.405	0.013	1.110	0.130	0.188	0.291
380	PCP_22	0.023	0.164	0.250	0.239	0.399	0.128	0.189	0.208	0.001	0.634	0.133	0.192	0.295
400	PCP_08	0.087	0.653	0.751	0.816	0.727	0.254	0.302	0.430	0.014	1.495	0.134	0.191	0.292
420	PCP_15	0.126	0.527	0.569	0.559	0.526	0.189	0.223	0.323	0.006	1.280	0.134	0.192	0.291
440	PCP_02	0.019	0.205	0.274	0.239	0.329	0.116	0.138	0.199	0.001	0.476	0.133	0.190	0.290
460	PCP_00	0.051	0.242	0.360	0.342	0.615	0.172	0.254	0.281	0.004	1.178	0.137	0.199	0.310
480	PCP_03	0.027	0.272	0.426	0.403	0.697	0.218	0.322	0.356	0.002	0.945	0.138	0.200	0.311
500	PCP_19	0.006	0.169	0.203	0.201	0.310	0.127	0.151	0.218	0.001	0.649	0.136	0.196	0.302
520	PCP_04	0.122	0.589	0.716	0.800	0.568	0.217	0.256	0.368	0.011	1.340	0.136	0.195	0.302
540	PCP_10	0.018	0.188	0.230	0.230	0.278	0.110	0.129	0.185	0.010	0.521	0.133	0.192	0.295
560	Kansas 2 NE	0.050	0.385	0.447	0.434	0.514	0.169	0.198	0.283	0.001	0.954	0.137	0.198	0.309
580	PCP_13	0.013	0.200	0.241	0.240	0.364	0.131	0.153	0.219	0.006	0.563	0.136	0.195	0.297
600	PCP_01	0.042	0.421	0.488	0.480	0.448	0.172	0.205	0.291	0.002	1.084	0.132	0.188	0.287
620	Tahlequah	0.021	0.284	0.321	0.310	0.399	0.100	0.119	0.170	0.000	0.754	0.126	0.180	0.273
640	Webbers	0.048	0.281	0.294	0.295	0.232	0.082	0.096	0.138	0.004	0.940	0.126	0.179	0.274
660	Odell 2N	0.132	0.731	0.745	0.776	0.628	0.187	0.221	0.304	0.019	1.875	0.136	0.198	0.305
	Mean	0.051	0.378	0.433	0.453	0.485	0.180	0.216	0.298	0.006	1.063	0.132	0.190	0.293
	Max	0.132	0.731	0.874	1.022	0.779	0.399	0.428	0.581	0.036	2.118	0.138	0.200	0.311
	Min	0.004	0.162	0.169	0.197	0.232	0.082	0.096	0.138	0.000	0.417	0.122	0.176	0.270
	Target Rates (low)	0.05	0.50	0.50	0.50	0.30	0.15	0.15	0.25	0.00	1.00	0.05	0.10	0.20
	Target Rates (high)	0.15	1.50	1.50	1.50	1.00	0.30	0.30	0.50	0.01	3.00	0.25	0.50	0.50

Instream Sediment Calibration Results

Sediment, or TSS (Total Suspended Solids), is often considered the most difficult and challenging water quality constituents to model. Lack of adequate sediment data, especially during storm events, lack of bed characterization data which has a major influence on the model results, and lack of sediment particle size information for both bed materials and storm samples all contribute to the difficulties in accurately simulating TSS. For these reasons, and others, simulated and observed TSS values are commonly displayed with a logarithmic scale, demonstrating the wide range in values commonly observed. Figure 4.8 and Figure 4.9 show TSS model comparisons for the Stateline (Reach 630) and Tahlequah (Reach 870), respectively; for the Stateline (Illinois River south of Siloam Springs, USGS gage 07196900) data were provide by both USGS (blue dots) and AWRC (green dots). The plots show both the arithmetic scale (top graph) and the log scale (bottom graph) to demonstrate the visual differences when assessing model results. Complete results for all calibration sites are provided in the FINAL IRW Model Report (MBI et al., 2015) Appendix B (separate document).

In reviewing these Sediment/TSS results, the calibration objective is usually to attempt to match the range of concentrations in the observed data and the general pattern and magnitude of observed TSS data for both storm and non-storm periods; it is usually difficult, if not impossible to force the model to match or approximate each of the observed data points. The TSS simulations shown in these figures are consistent with the available observed data and with the simulations at the other sites. The model provides a good representation of TSS data at both of these sites, and most of the other calibration sites as presented in the Final IRW Model Report, Appendix B. Thus, the IRW model provides a good representation of the sediment/TSS behavior within the IRW and a sound basis for the subsequent water quality calibration.

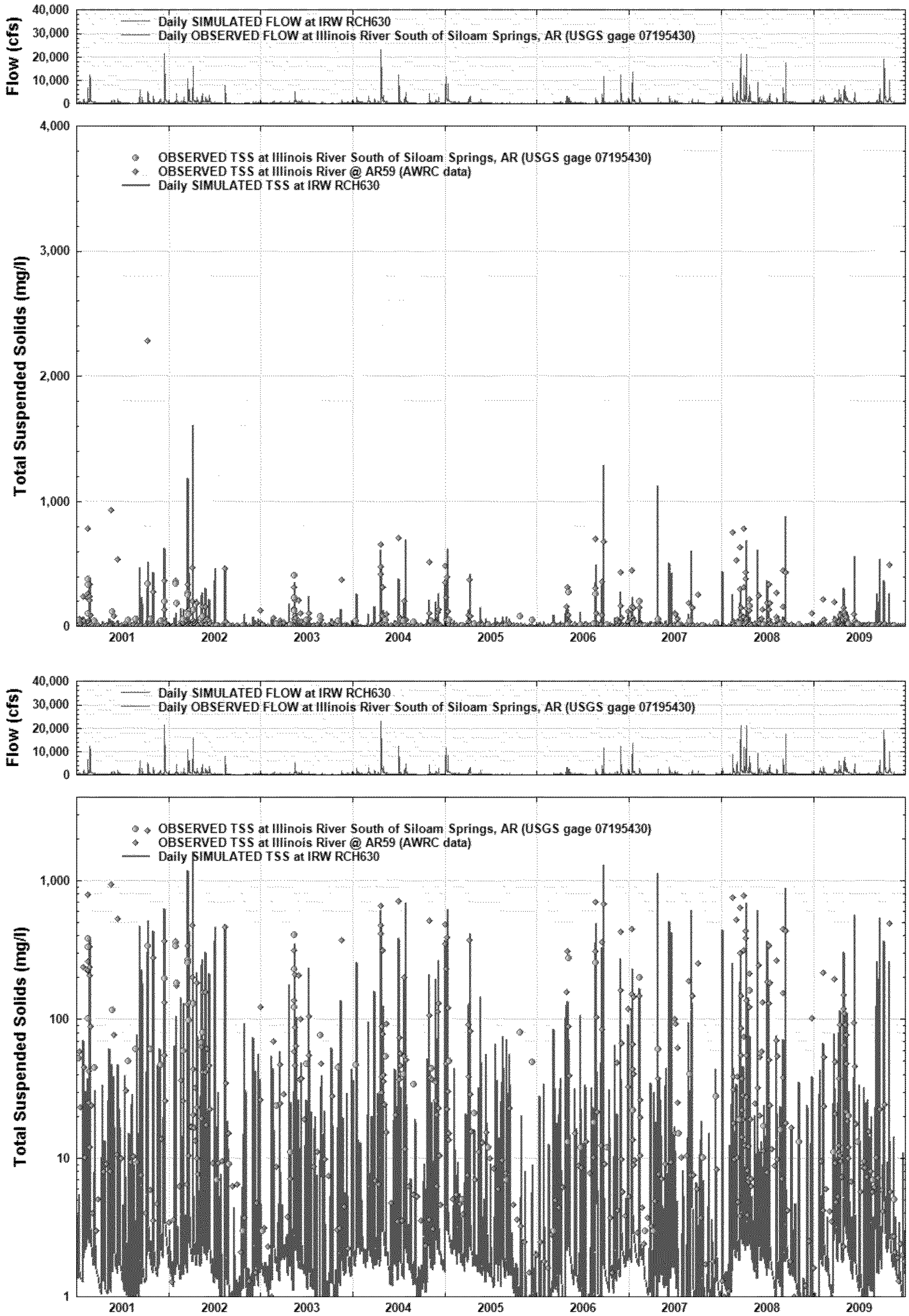


Figure 4.8 Sediment Calibration Plots for Illinois River south of Siloam Springs (Reach 630)

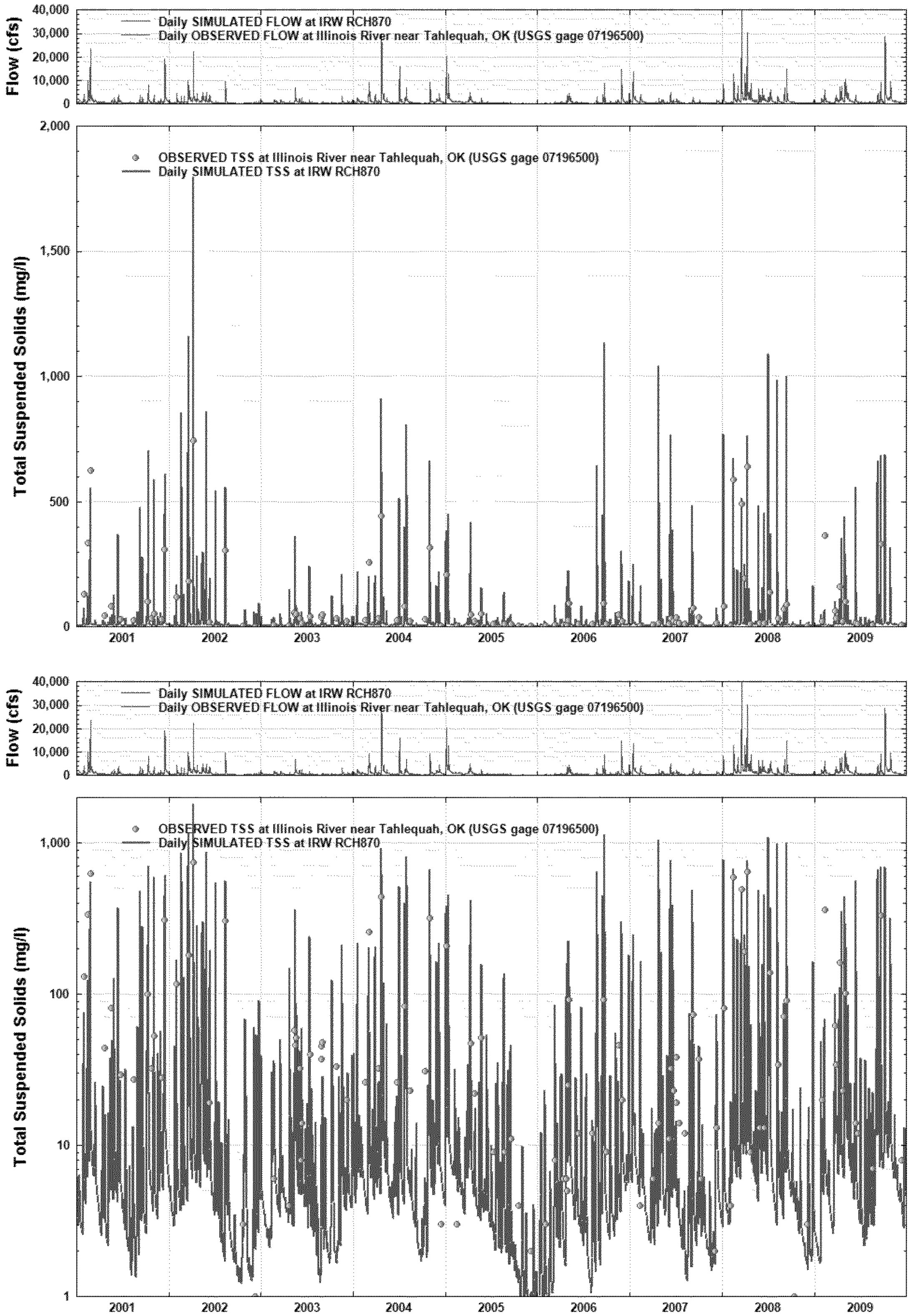
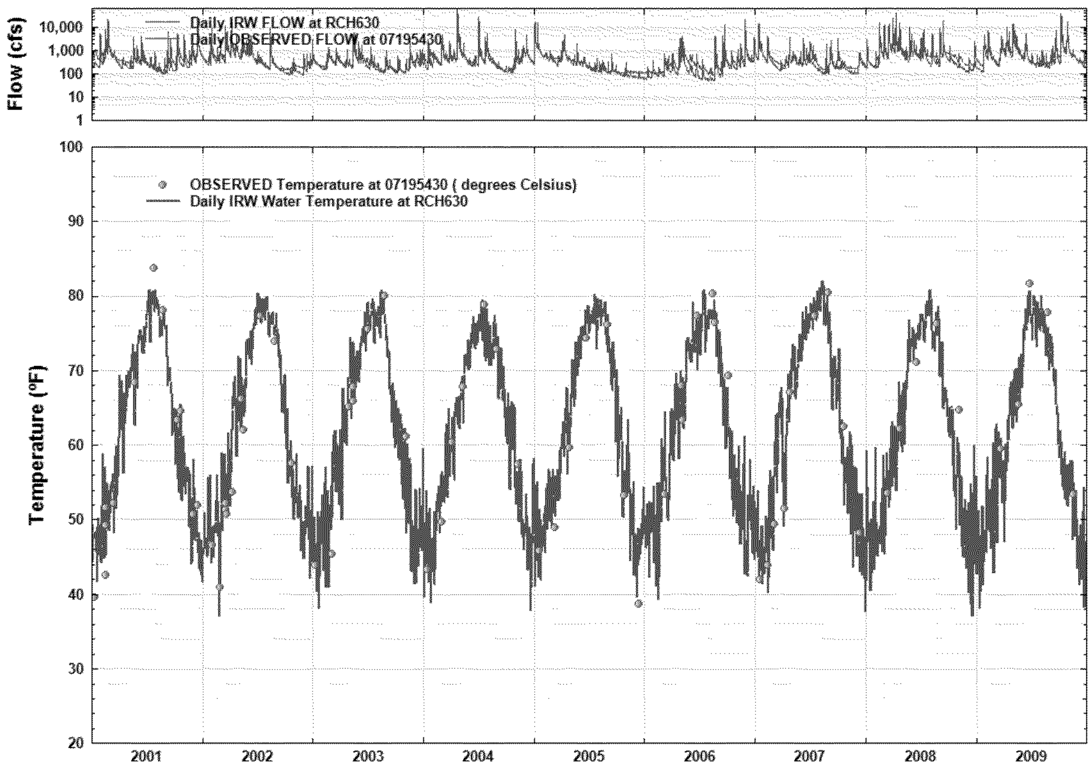


Figure 4.9 Sediment Calibration Plots for Illinois River near Tahlequah (Reach 870)

Water Temperature Calibration and Validation Results

Water temperature is an environmental characteristic that impacts all the aquatic water quality processes. As such, it is an important variable to accurately represent. The energy balance calculations that are used to model water temperature with the HSPF stream reach module are well-established, and often produce very good to excellent simulations. Figure 4.10 and Figure 4.11 provide the water temperature calibration (top graphs) and validation (bottom graphs) results the Stateline (Reach 630), and Tahlequah (Reach 870), respectively. Results for the other calibration sites are included in Final IRW Model Report, Appendix C.



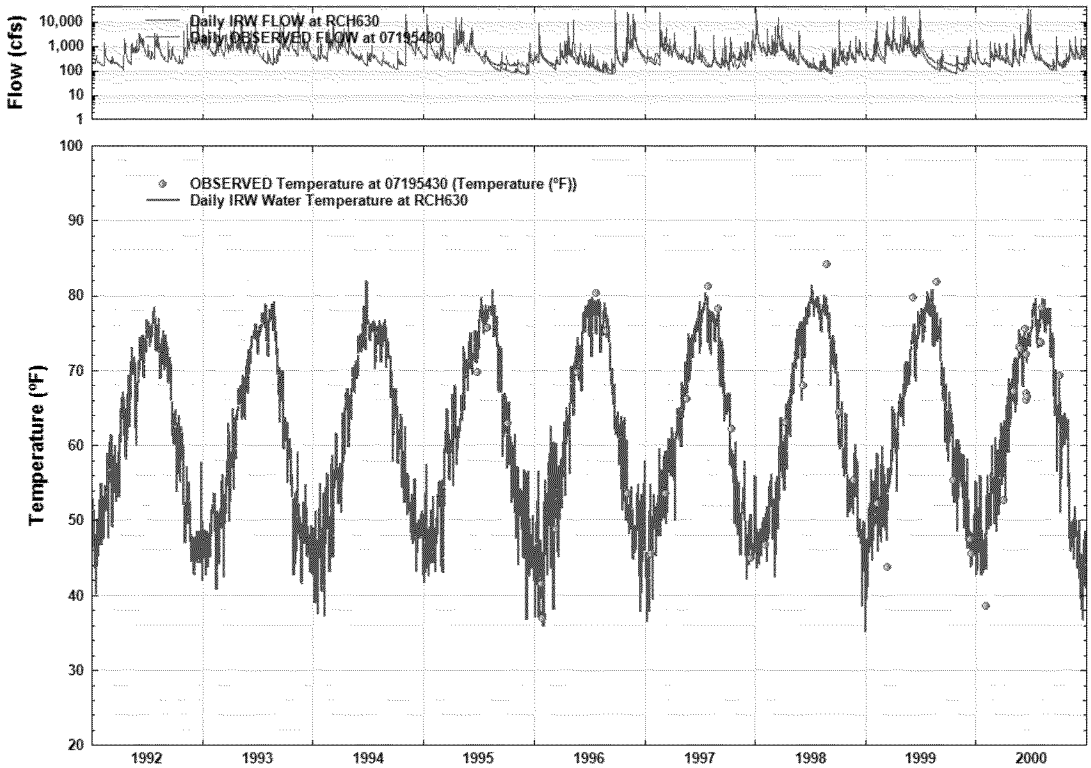


Figure 4.10 Water Temperatures Graphs for Illinois River South of Siloam Springs (Reach 630) for Calibration (top) and Validation (bottom) periods

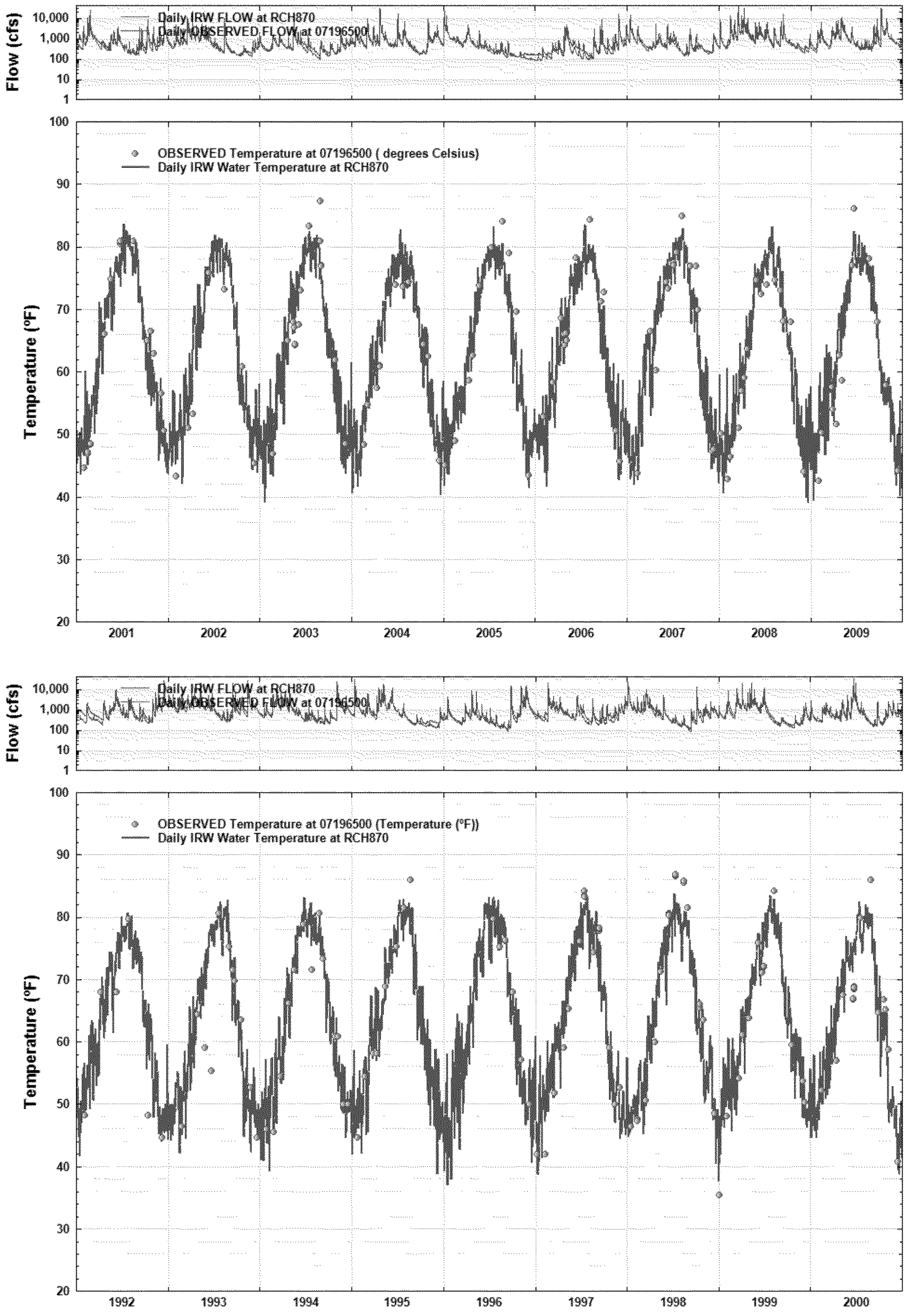


Figure 4.11 Water Temperatures Graphs for Illinois River near Tahlequah (Reach 870) for Calibration (top) and Validation (bottom) periods

Nonpoint Loading Calibration and Results

As noted earlier, the nonpoint loading simulations in the IRW HSPF model are based on two separate procedures and modules within the HSPF code. All pasture areas, which receive fertilizer, manure and litter applications of nutrients, are represented by the AGCHEM module, while all the other land areas are represented by the simpler PQUAL routines (and IQUAL routines for impervious surfaces). This section summarizes the resulting loading rates for all nonpoint sources, as a function of land use categories, climate forcing functions, and land characteristics throughout the IRW. The Final IRW Report (Section 4.4.1) discusses the PQUAL/IQUAL application to the non-pasture lands, while Section 4.4.2 specifically discusses the application of the AGCHEM module, its parameterization, litter applications, and the resulting loading rates from all the pasture areas. As a result of the climate variation in the IRW, along with soils, slope, and land use characteristics, the resulting nonpoint source loading rates calculated by the model vary throughout the watershed. A summary of the mean, minimum, and maximum annual nonpoint source rates by constituent and land use, calculated by the model in lbs/ac/yr, is listed in **Table 4.17**; a detailed listing for all 33 model segments is included in the Final IRW Report, Appendix E.

Since direct observations of loading rates is often limited, and rarely available for most modeled watersheds, "target" ranges are developed from all available local, and possibly regional information on nonpoint source contributions for each modeled constituent. 4-8 shows the target ranges developed to guide the calibration for the IRW. These ranges were developed from multiple modeling studies in Arkansas, Minnesota, Iowa and Maryland (See IRWM Model Report for specific study references). These loading rates reflect a large range due to varying climate, soils, slope, land use, and nutrient input conditions. Based on experience with the model and specifically in all these locations, including the IRW, the ranges shown in **Table 4.18** provide a reasonable comparison to judge acceptability of the nonpoint rates for the IRW. The goal is to maintain the majority of the loading rates within the target ranges and allow for any specific local IRW conditions that may indicate a preference or need for values in the lower or upper portions of the range. Thus, the ranges are general guidance to assess the acceptability of nonpoint simulation, and not absolute limits.

Table 4.17 Modeled Nonpoint Source Loading Rates (lb/ac/yr) for the IRW

Land Uses		Pervious											Impervious		
Metric	Nonpoint Source Constituent	Forest	Pasture1	Pasture1 - Litter	Pasture2	Pasture3	Grass/ Shrub/ Barren	Developed, Open	Developed, Low	Developed, Med/High	Wetlands	Cropland	Developed, Open	Developed, Low	Developed, Med/High
Mean	BOD	2.50	15.73	22.73	17.92	18.61	7.28	7.75	9.98	13.43	1.99	31.06	9.88	14.11	16.23
	NO3	3.78	8.12	2.66	8.02	7.94	6.43	8.34	9.56	10.93	2.75	18.14	2.26	3.61	4.06
	NH3	0.17	0.47	0.36	0.48	0.49	0.53	0.80	0.80	0.79	0.10	0.74	0.48	0.76	0.86
	LabileOrgN	0.13	0.83	1.20	0.95	0.99	0.39	0.41	0.53	0.71	0.11	1.64	0.52	0.75	0.86
	RefractoryOrgN	0.30	1.25	1.81	1.42	1.48	0.87	0.93	1.20	1.61	0.24	3.73	1.19	1.69	1.95
	TN	4.38	10.67	6.04	10.88	10.90	8.23	10.48	12.08	14.04	3.20	24.26	4.44	6.81	7.73
	PO4	0.03	0.57	2.47	0.57	0.58	0.46	0.22	0.28	0.35	0.01	0.86	0.26	0.38	0.42
	LabileOrgP	0.02	0.12	0.17	0.13	0.14	0.05	0.06	0.07	0.10	0.01	0.23	0.07	0.10	0.12
	RefractoryOrgP	0.03	0.34	0.50	0.39	0.41	0.08	0.09	0.11	0.15	0.02	0.36	0.11	0.16	0.19
	TP	0.08	1.02	3.14	1.09	1.13	0.59	0.37	0.47	0.60	0.05	1.44	0.45	0.64	0.72
Min	BOD	1.52	6.18	6.35	6.52	7.57	5.10	5.58	7.19	9.76	0.96	19.88	9.60	13.70	15.76
	NO3	2.28	5.84	1.73	5.75	5.67	4.77	6.19	7.14	8.19	1.28	12.98	2.16	3.45	3.88
	NH3	0.06	0.23	0.18	0.23	0.22	0.29	0.50	0.50	0.50	0.04	0.38	0.47	0.74	0.84
	LabileOrgN	0.08	0.33	0.34	0.35	0.40	0.27	0.30	0.38	0.52	0.05	1.05	0.51	0.73	0.83
	RefractoryOrgN	0.18	0.49	0.50	0.52	0.60	0.61	0.67	0.86	1.17	0.12	2.39	1.15	1.64	1.89
	TN	2.63	6.94	2.77	6.96	6.99	6.06	7.77	8.99	10.47	1.48	16.83	4.29	6.57	7.45
	PO4	0.02	0.28	0.46	0.28	0.29	0.23	0.13	0.17	0.20	0.01	0.43	0.25	0.36	0.40
	LabileOrgP	0.01	0.05	0.05	0.05	0.06	0.04	0.04	0.05	0.07	0.01	0.15	0.07	0.10	0.12
	RefractoryOrgP	0.02	0.13	0.13	0.14	0.16	0.06	0.06	0.08	0.11	0.01	0.23	0.11	0.16	0.18
	TP	0.05	0.49	0.73	0.53	0.54	0.33	0.25	0.31	0.39	0.02	0.81	0.43	0.62	0.69
Max	BOD	4.86	33.12	60.41	35.85	40.87	9.68	10.71	13.55	17.75	3.70	46.72	10.71	15.30	17.60
	NO3	6.88	12.42	4.59	12.26	12.12	9.29	12.09	13.85	15.85	5.24	27.02	2.54	4.07	4.57
	NH3	0.48	1.38	1.10	1.43	1.42	0.91	1.19	1.19	1.18	0.26	1.44	0.51	0.81	0.92
	LabileOrgN	0.26	1.75	3.20	1.90	2.16	0.51	0.57	0.72	0.94	0.20	2.47	0.57	0.81	0.93
	RefractoryOrgN	0.58	2.63	4.80	2.85	3.25	1.16	1.29	1.63	2.13	0.44	5.61	1.29	1.84	2.11
	TN	8.12	18.18	13.68	18.13	18.12	11.87	15.05	17.29	20.03	6.10	36.54	4.91	7.52	8.53
	PO4	0.06	1.26	6.64	1.25	1.28	0.70	0.41	0.47	0.59	0.02	1.58	0.30	0.43	0.48
	LabileOrgP	0.04	0.24	0.44	0.26	0.30	0.07	0.08	0.10	0.13	0.03	0.34	0.08	0.11	0.13
	RefractoryOrgP	0.06	0.67	1.16	0.77	0.88	0.11	0.12	0.16	0.20	0.04	0.54	0.12	0.18	0.20
	TP	0.16	2.18	8.24	2.18	2.28	0.86	0.59	0.70	0.91	0.09	2.40	0.50	0.72	0.81

Table 4.18 "Target" Nonpoint Source Loadings Rates (lb/ac/yr) for the IRW

	Forest		Pasture*		Developed		Cropland		Impervious	
Constituent	Low	High	Low	High	Low	High	Low	High	Low	High
BOD/Organics	2	10	5	70	5	15	5	50	3	20
NO3	1	10	2	15	5	15	10	30	2	5
NH3	0.1	1.0	0.2	1.5	0.2	2.0	0.5	2.0	0.5	1.5
TN	2	8	2	25	5	20	10	50	3	10
PO4	0.02	0.10	0.2	2.0	0.1	1.0	0.3	2.0	0.2	0.7
TP	0.05	0.50	0.5	2.5	0.2	1.5	0.5	3.0	0.3	1.0

*excludes pasture receiving litter applications

Instream Water Quality Calibration

Calibration of the instream water quality parameters that control the aquatic processes, along with nutrient fate and transport, is normally the final step in the watershed water quality calibration process. However, given that the entire effort is often an iterative process, it is fairly common to re-iterate the component steps in the process with a need to re-examine the sediment and nonpoint source loading rates, and even sometimes the hydrologic calibration, in an attempt to improve flow simulations for time periods when data is available for the water quality calibration effort. In many cases, either under or over simulation of flows will have dramatic impacts on the calculated concentrations that are the focus of the calibration effort. This is especially true during extreme high flow, or low flow, conditions, such as those that occurred in 2005-2006, in the middle of the calibration period.

Water quality calibration, analogous to hydrologic calibration, follows an upstream to downstream approach to implement successive improvements in model results as we 'follow the water' from the smaller headwater creeks, to moderate streams, and ultimately to the major conveyance of the Illinois River. For the IRW, this approach started on the Baron Fork at Dutch Mills (Reach 706), Osage Creek near Elm Springs (Reach 316), Illinois River at Savoy (Reach 150), and as noted earlier, Ballard Creek on County Road 76 (Reach 609). As the upstream simulations demonstrated improvements, the focus moved downstream to the Illinois River south of Siloam Springs, AR (Reach 630), Illinois River near Watts, OK (Reach 640), Sager Creek near West Siloam Springs, OK (Reach 516) and Flint Creek near Kansas, OK (Reach 523). The concluding efforts focused on the Illinois River near Tahlequah, OK (Reach 870), Baron Fork at Eldon, OK (Reach746), and Caney Creek near Barber, OK (Reach 912). As the calibration was concluded, the parameter values were extended to the areas around Lake Tenkiller that drain directly to the Lake.

Figures 4.12 through 4.15 show the water quality calibration results for DO, TN, PO4-P and TP for the Illinois River near the AR/OK Stateline (Model Reach 630, USGS Gage 17195430) and at the Illinois River near Tahlequah, OK (Model Reach 870, USGS 07196500). The IRW Final Report, Appendix B includes a complete set of graphs for all the simulated water quality constituents for all 11 gages subject to calibration, and provides a more detailed discussion of the water quality calibration process for the IRW. From a review of all these calibration results, the following statements and conclusions are provided:

a. For the majority of the modeled constituents, the simulated values provide reasonable agreement with the observed data, especially when sufficient data is available for both storm and non-storm periods to support a valid calibration. For a modeling assessment, we define 'reasonable agreement' as comprised of three components:

    i. The simulated values are within a factor of 2 of the observations, i.e., the majority of simulated daily concentration values are within 50% to 200% of the observations, and
    ii. The simulated values demonstrate a <u>range</u> of values (low to high) comparable to the observations, and
    iii. The pattern of the simulated daily time series is similar to the peaks and valleys of the observations, when the population of the observations is adequate to define such a pattern and possibly seasonal cycling.

b. The DO simulation shows a very good seasonal pattern consistent with the observed data, and the peaks and valleys are generally well represented. However, there are greater deviations in some years, and especially during the drought years of 2005-2006.

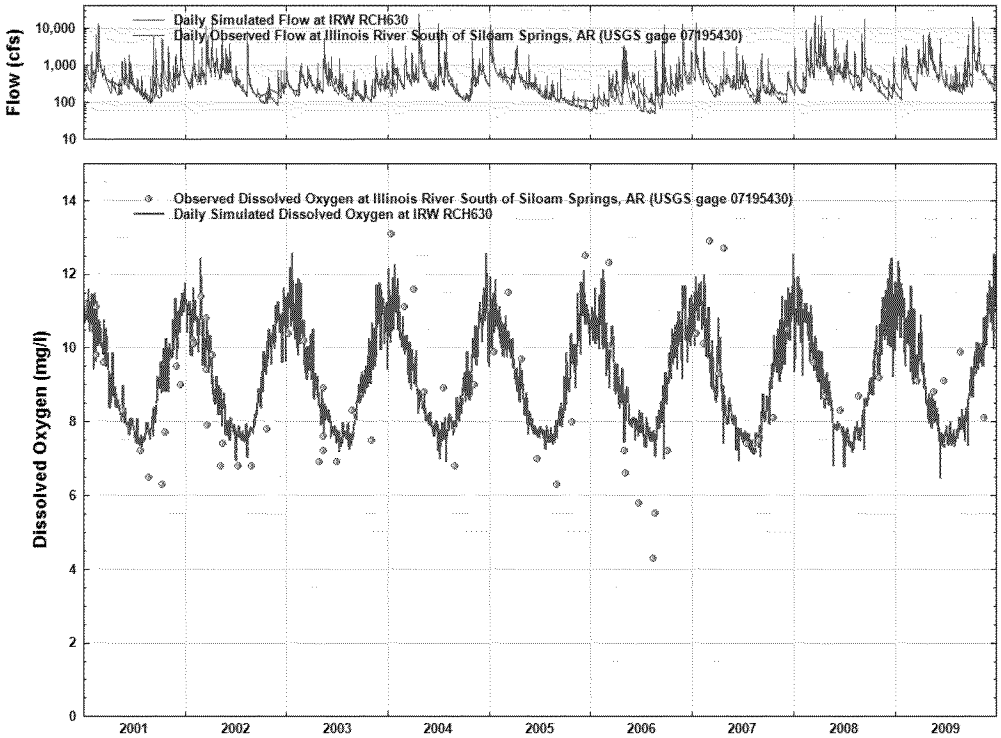
c. For the two major sites of concern, the IR south of Siloam Springs (Reach 630), and the IR near Tahlequah (Reach 870), the simulations demonstrate good overall agreement for most all of the constituents simulated. Overall, the P components are generally better simulated than the N components as P was the major focus of this study due to the OK scenic rivers standard based on TP.

d. Our overall assessment of the water quality calibration is that the model demonstrates reasonable agreement with most observations for DO, TP, NO3-N, Organic N, and TN for most of the calibration sites. The larger mainstem sites, such as IR at Savoy, Osage Creek, IR South of Siloam Springs, IR near Watts, Baron Fork at Eldon, and IR near Tahlequah definitely show better agreement than the smaller sites.

e. As discussed in Section 2.6.3 of the Final IRW Report, for a number of gage sites there are substantial differences in the amount and peak values of data collected during storm events versus non-storm periods. The TSS results for Osage demonstrate the significant difference in peak concentrations for samples collected during normal bimonthly sampling for much of the period from 2001 to 2006, versus those data for storm periods collected from 2007 to 2009. Similar patterns are seen for PO4-P, TP, and NH4-N at other sites. The result is that calibrating to only non-storm data will likely lead to the model under-estimating concentrations and loads. Consequently, our calibration efforts focused more on the data periods when storm data had been collected. Also, this is a primary rationale for our 'reasonable agreement' criteria of between 50% and 200% of observations.

f. The drought conditions in 2005-06 had a major impact on model results, causing significant over-estimation of nutrient forms, especially both P and N forms and DO. Part of the cause is the under simulation of flow during that drought which contributed to the over-estimation for many concentrations.

In summary, the overall water quality calibration for the IRW demonstrates overall reasonable agreement with the majority of the observed data, especially for the IR mainstem sites, and for the two major sites of concern, at the AR/OK state line and at Tahlequah. The Final IRW Report provides complete water quality calibration results for all sites, along with more detailed discussion of the calibration procedures and results.



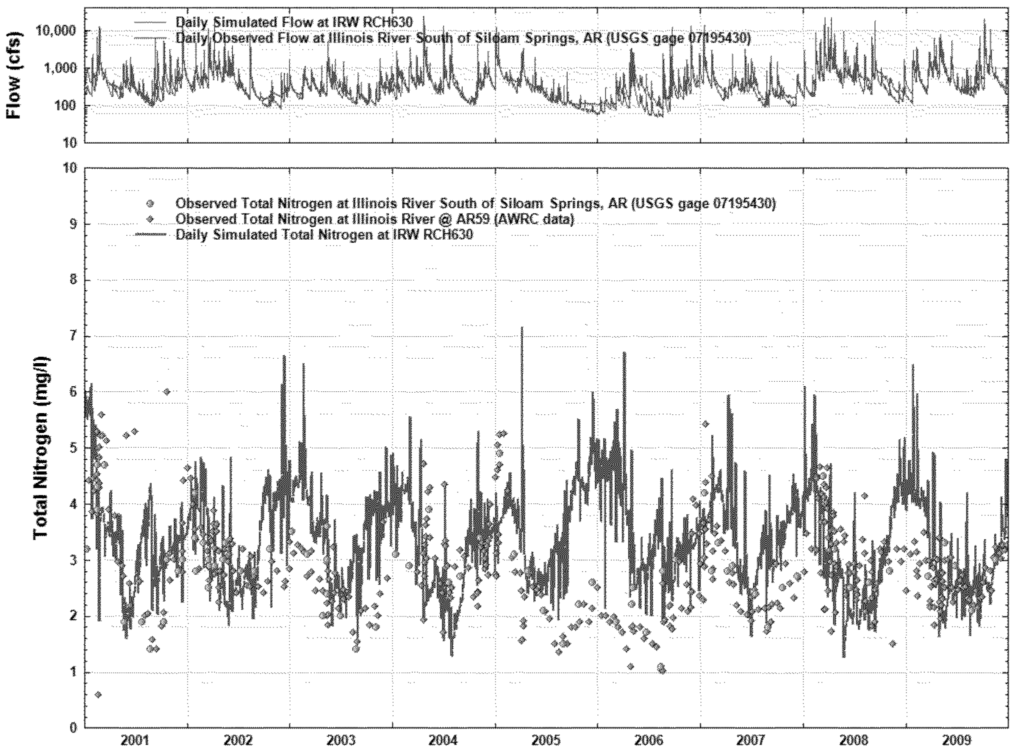


Figure 4.12 Simulated and Observed DO (top) and TN (bottom) at Illinois River below Siloam Springs, AR (Reach 630, USGS 07195430)

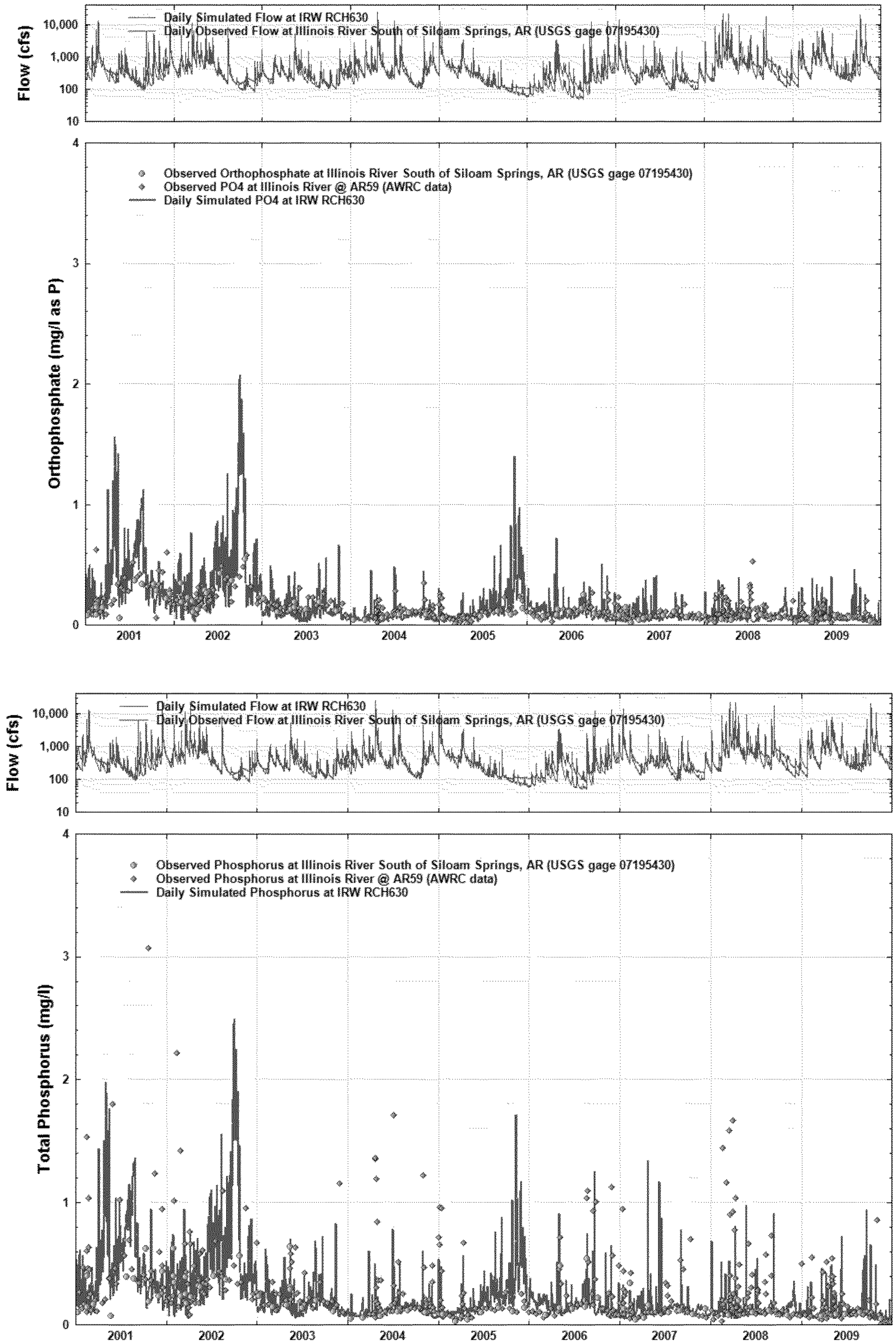


Figure 4.13 Simulated and Observed PO4-P (top) and TP (bottom) at Illinois River below Siloam Springs, AR (Reach 630, USGS 07195430)

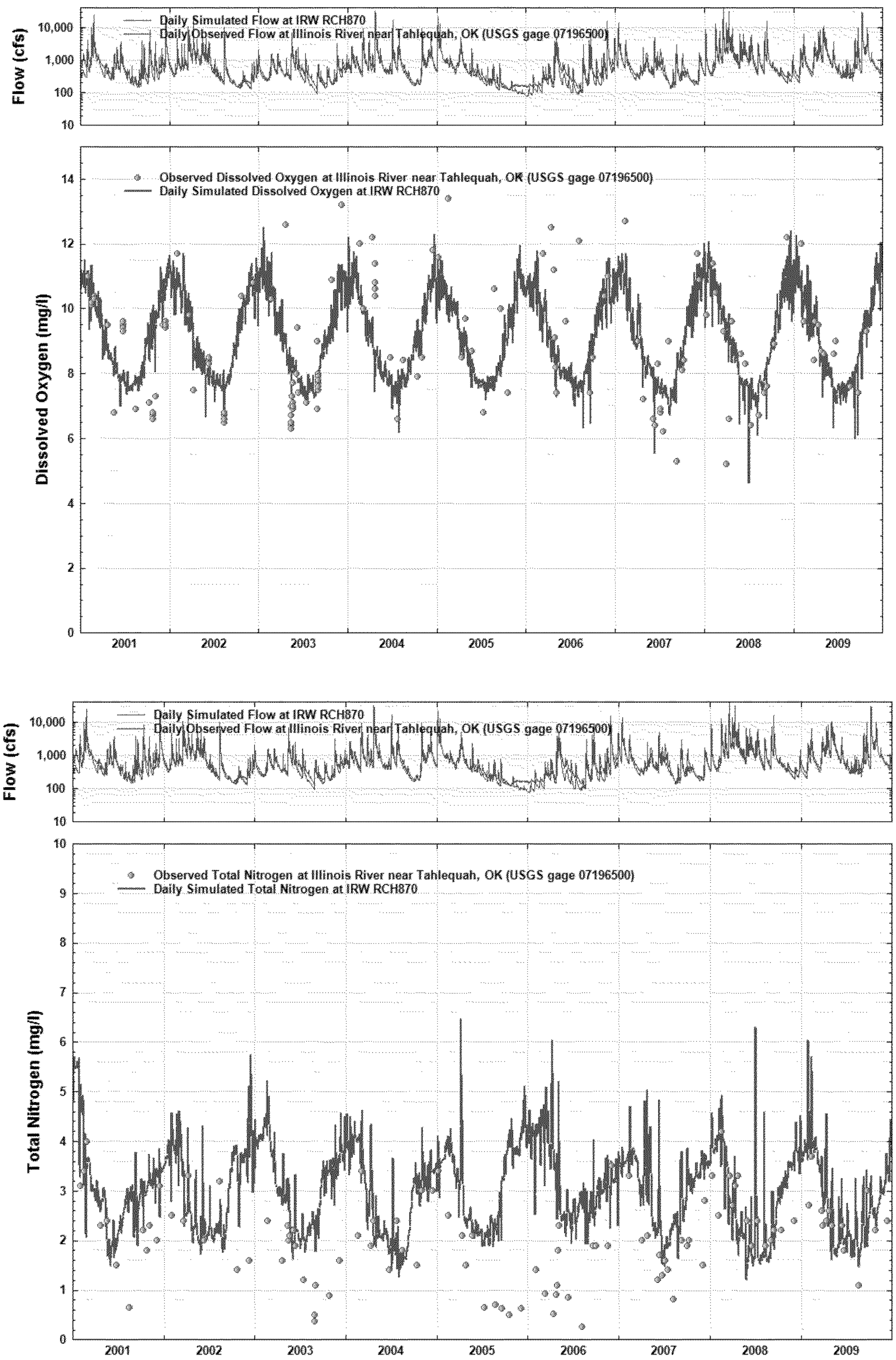
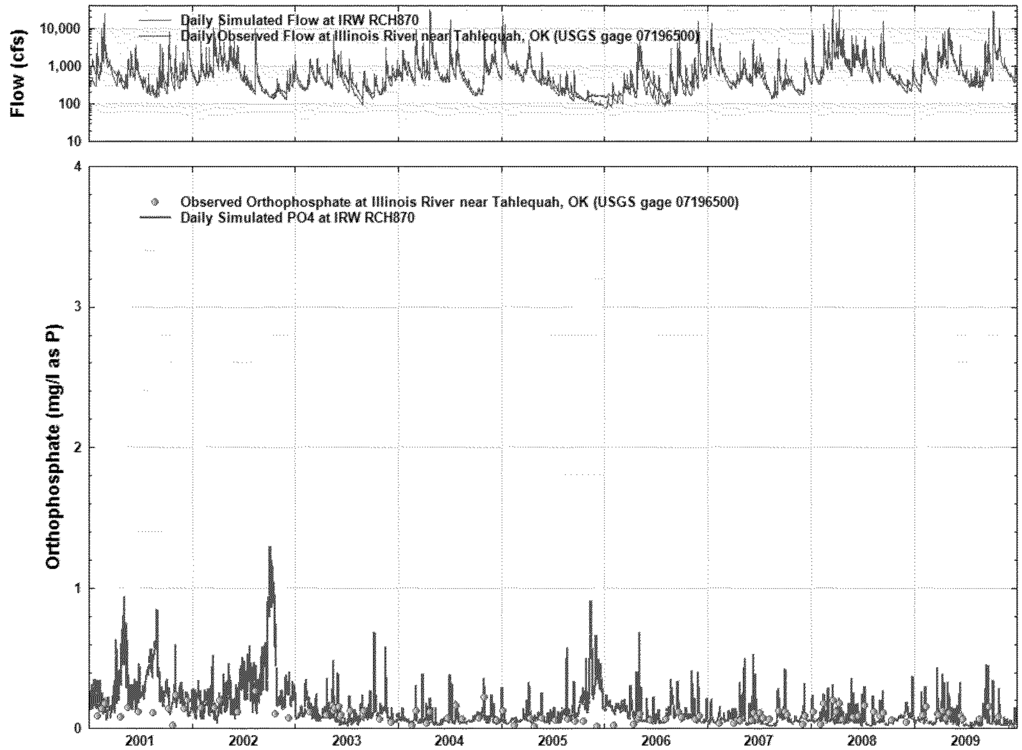


Figure 4.14 Simulated and Observed DO (top) and TN (bottom) at Illinois River near Tahlequah, OK (Reach 630, USGS 07196500)



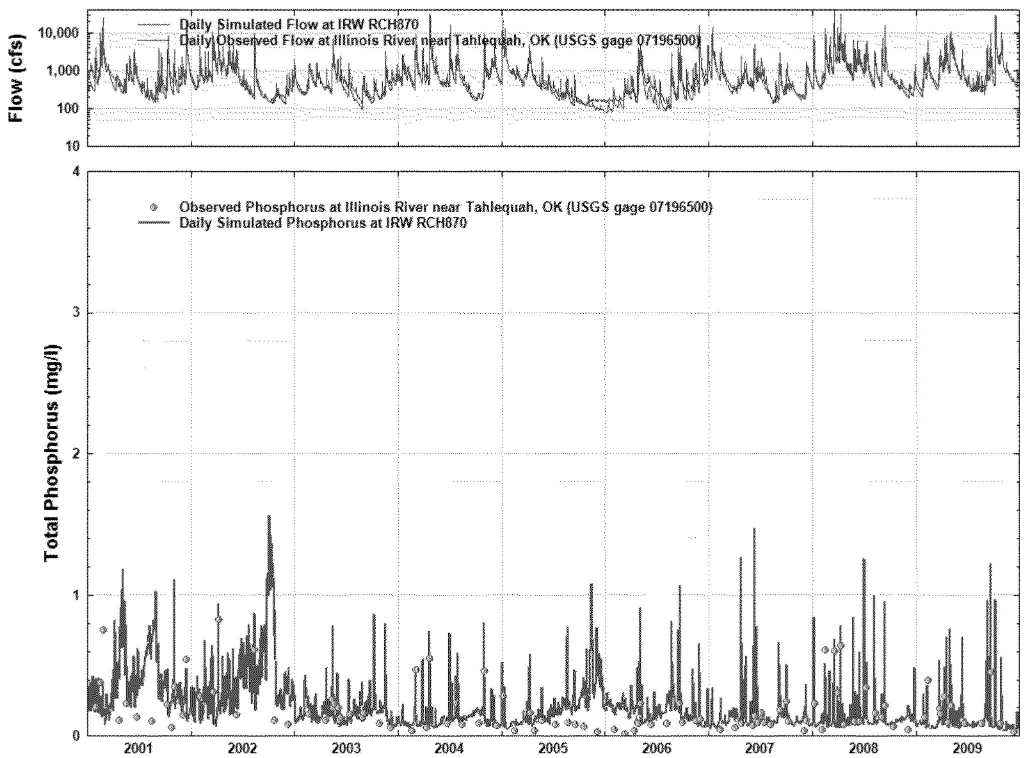


Figure 4.15 Simulated and Observed PO4-P (top) and TP (bottom) at Illinois River near Tahlequah, OK (Reach 870, USGS 07196500)

Final Changes to IRW Model Calibration

Upon submittal of the Final IRW Model Report, EPA Region 6 and their Technical Work Group (WG) reviewed the modeling procedures and results, and performed additional selected calibration efforts in response to questions and concerns from the WG members, including various State representatives of both AR and OK. A series of model runs were performed with various parameter changes, in an effort to improve the agreement with observed data and respond to concerns from the WG. Through that effort, the following changes were implemented:

a. The monthly distribution of litter applications was adjusted to focus more of the application during the spring months, as opposed to equal applications throughout the March to November period. This appeared to somewhat improve the spring simulation results as determined by the root-mean square errors (RMSE) of the instream concentrations.
b. The litter applications were also adjusted from a distribution of 30% in the surface layer and 70% in the Upper Zone layer, to a 10%/90% distribution between the surface and upper layers. This was also based on several model runs and reviews of the RMSE of the instream concentrations.
c. The instream nitrification rates (KTAM20, KNO220), denitrification rate (KNO320) and denitrification threshold (DENOXT) were all adjusted to improve the Total Nitrogen (TN) simulation, especially during the summer months. The final parameter values were established from numerous simulation runs with alternative parameter adjustments, and subsequent calculations of the RMSE of the instream TN concentrations.

Model results from these final simulations are available from the EPA Region 6.

4.2. EFDC Lake Model and Watershed-Lake Model Linkage

The objective of a TMDL study is to estimate allowable pollutant loads expected to achieve compliance with water quality criteria. The allowable load is then allocated among the known pollutant sources in the watershed so that appropriate control measures can be implemented to reduce pollutant loading. To determine the effect of watershed management measures on in-lake water quality, it is necessary to establish a cause-effect linkage between the external loading of sediments, nutrients and organic matter from the watershed and the waterbody response in terms of lake water quality conditions for sediments, nutrients, organic matter, dissolved oxygen and chlorophyll-*a*. This section describes an overview of the water quality modeling analysis of the EFDC linkage between water quality conditions in Tenkiller Ferry Lake and HSPF watershed pollutant loading. Appendix C of this TMDL report presents a description of the EFDC model, setup of the model, data sources, and model results for existing conditions and analysis of the effect of watershed load reductions on lake water quality.

4.2.1 EFDC Model Description

EFDC is an advanced surface water modeling package for simulating three-dimensional (3-D) circulation, salinity, water temperature, sediment transport and biogeochemical processes in surface waters including rivers, lakes, reservoirs, estuaries, and coastal systems. The EFDC model has been supported by EPA over the past decade as a public domain, peer reviewed model to support surface water quality investigations including numerous TMDL evaluations

(Ji, 2008). EFDC directly couples the hydrodynamic model (Hamrick, 1992, 1996) with sediment transport (Tetra Tech, 2002), water quality (Park et al., 2000; Hamrick, 2007) and sediment diagenesis models (Di Toro, 2001). EFDC state variables include suspended solids, dissolved oxygen, nutrients (N, P), organic carbon, algae, sediment bed organic carbon and nutrients and benthic fluxes of nutrients and dissolved oxygen. The EFDC model is time variable with model results output at user-assigned hourly time intervals. The EFDC model requires input data to characterize lake geometry (shoreline, depth, surface area, and volume), time varying watershed inputs of flow and pollutant loads, time varying water supply withdrawals and release flows, and kinetic coefficients to describe water quality interactions such as nutrient uptake by algae. Observed water quality data collected at lake monitoring sites are used for calibration and validation of the model results to observations. Model setup, data input, and post-processing of model results is facilitated with the EFDC_Explorer graphical user interface (Craig, 2012).

4.2.2 Data Sources and EFDC Model Setup

Data Sources. Data sources used for development of the lake model included lake water quality monitoring by CDM/USGS and OWRB; lake level, releases and storage volume monitoring by the USACE Tulsa District; and meteorological data from NOAA NCDC and Oklahoma MESONET stations in the vicinity of the watershed. Detailed bathymetric data is available from a 2005 survey that was conducted to support the collection of sediment cores (Fisher, 2008; Fisher et al., 2009) and development of a laterally-averaged CE-QUAL-W2 hydrodynamic and water quality model of Lake Tenkiller (Wells et al., 2008).

The Tenkiller Lake EFDC water quality model was calibrated and validated at seven (7) OWRB stations and four (4) CDM/USGS stations. Although there are very limited OWRB data to generate meaningful statistics for model performance, there is sufficient CDM monitoring data to support calculation of model performance statistics to evaluate comparisons between observed data and simulated results. The CDM/USGS monitoring stations are spatially distributed throughout the lake: LK-01 represents the deep portion of the lake; LK-02 is located in the middle of the lake; LK-04 represents the upper portion of the lake; and LK-03 is located in the transition zone between the riverine environment of the Illinois River and the lacustrine environment of Tenkiller Lake. Tables of observed water quality data used for EFDC lake model development are presented in Appendix D of this report.

EFDC Model Domain. The EFDC model allows for the physical representation of the lake with a horizontal mesh of curvilinear grid or Cartesian grid cells to account for the shoreline, embayments, and bathymetry, particularly the deeper parts of the lake (Figure 4.16). The EFDC model grid, developed with Sigma Zed vertical layers to significantly reduce pressure gradient errors, consists of 833 horizontal model grids. Unlike the sigma vertical layer approach which uses a fixed number of layers for all cells in the model domain, the Sigma Zed approach allows for specification of a spatially variable number of vertical layers over the model domain. Figure 4.16 shows a plan view map of the 833 horizontal cells that has been developed for the current model for Lake Tenkiller. Forty (40) uniform vertical Sigma Zed layers are used to represent vertical resolution in the deep areas of the lake while 2 to 10 layers are used to represent shallow areas of the lake.

Boundary Conditions. The EFDC lake model requires specification of external boundary data to describe: (1) flow and pollutant loading from watershed tributaries and distributed runoff; (2) flow releases at the dam; (3) withdrawals from water supply intakes; (4) wind forcing, evaporation, precipitation, and other meteorological forcing; and (5) atmospheric deposition of nutrients.

As described in Section 3, flow and pollutant loading from the watershed was provided by the HSPF model as time series inflow data for tributaries and overland runoff. Tributary inflows included Illinois River, Baron Fork Creek, Canery Creek, Dry Creek, and Chicken Creek. Stoichiometric transformations of HSPF water quality results as input to state variables needed for the EFDC lake model are described in Appendix C of this report.

Water supply withdrawal data for Tenkiller Ferry Lake were not readily available. A flow balance analysis was estimated using all inflow data including all HSPF simulated watershed flows, rainfall and all outflows including evaporation and flow releases at the dam. A flow balance was computed to implicitly account for water supply withdrawals and to ensure that the EFDC model simulation of lake stage was in good agreement with observed lake stage records.

The EFDC model requires time series data to describe the effect of meteorological forcing and winds on lake circulation processes. Cloud cover data were obtained from the NOAA station at Tahlequah Municipal Airport. Other meteorological data and wind speed and direction data were obtained from the Oklahoma MESONET database at Station COOK. Meteorological data needed for the model includes wind, air temperature, air pressure, relative humidity, precipitation, evaporation, cloud cover and solar radiation.

The EFDC model requires specification of wet and dry atmospheric deposition of nitrogen and phosphorus over the entire surface area of the lake. Atmospheric deposition of nutrients is represented using the same constant loading rate for both model calibration and validation to existing conditions (2005-2006) and model evaluations of watershed load reduction scenarios. Since atmospheric deposition is uncontrollable on the local watershed scale, there is no load allocation for atmospheric deposition of nutrients for the TMDL. For Tenkiller Ferry Lake, wet and dry deposition data for nitrogen, presented in Appendix C, was estimated as the average of annual data from 2005-2006 for ammonia and nitrate from the National Atmospheric Deposition Program (NADP) for Station AR27 (Fayetteville, AR) and the Clean Air Status and Trends Network (CASTNET) Station CHE185 (Cherokee Nation). Wet deposition input of ammonia and nitrate is based on a constant concentration in rainfall and the time series of precipitation assigned for 2005-2006 input conditions. As data were not available from the CASTNET or NADP sites for deposition of phosphate, dry deposition for phosphate was estimated using the CASTNET and NADP data for nitrogen with annual average N/P ratios for atmospheric deposition of N and P reported for 6 sites located in Iowa (Anderson and Downing, 2006). Annual average wet phosphate concentration was estimated in proportion to the Dry/Wet ratio for phosphate deposition fluxes reported by Anderson and Downing (2006).

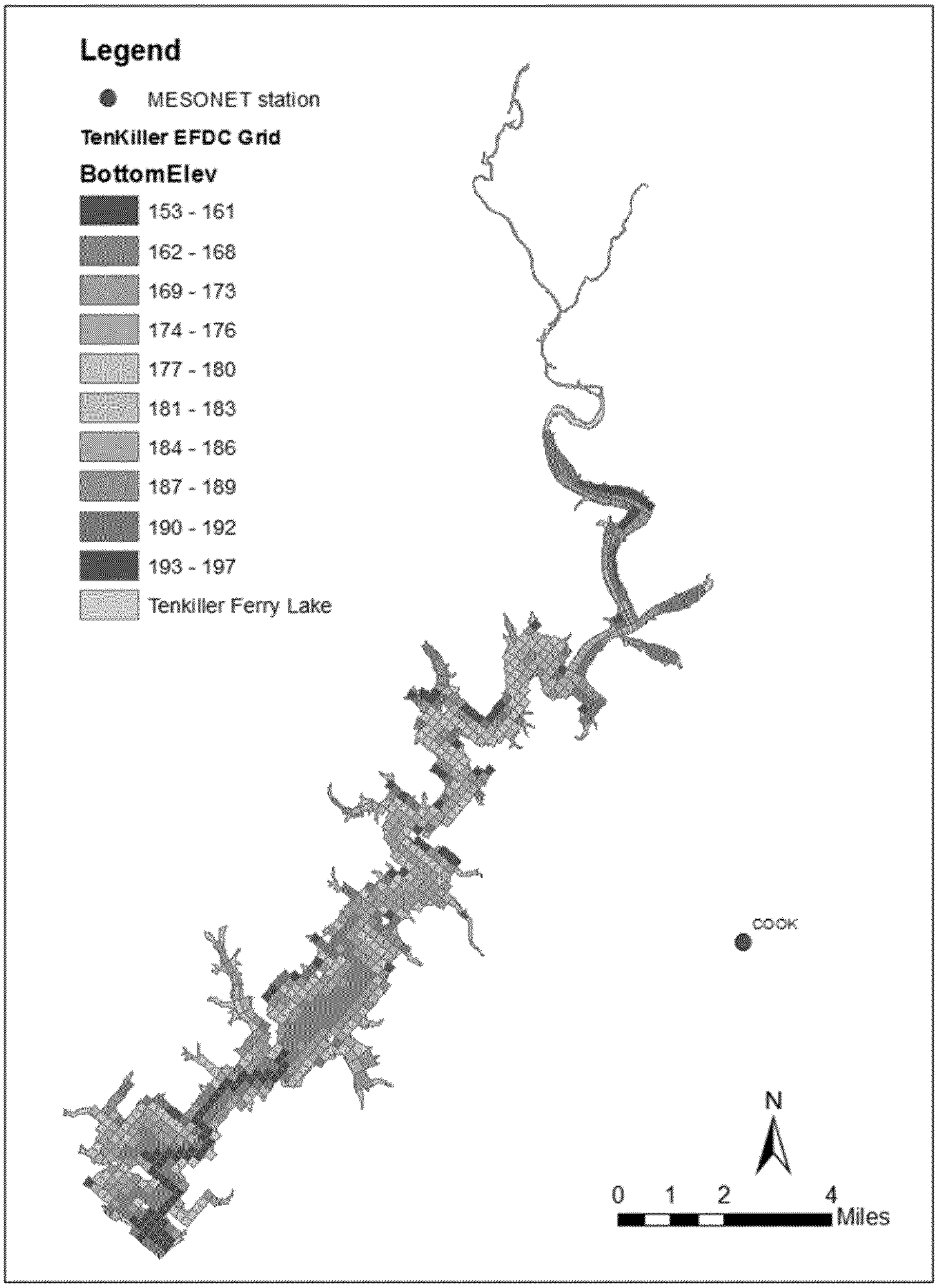


Figure 4.16 Tenkiller Ferry Lake Computational Grid and Bottom Elevation (m, NAVD88)

<u>Initial Conditions</u>. As a time varying model, EFDC requires the specification of initial distributions of all the model state variables at the beginning of the model simulation period in

January 2005. The spatial distribution of initial conditions for the model is based on simulated conditions at the end of the 1-year spin-up run. Restart conditions, written for all state variables of the model at the end of the spin-up run, were used to assign a simulated set of initial conditions for January 2005 that accounted for spatial variability of conditions in the water column and sediment bed.

4.2.3 EFDC Model Calibration and Validation to Existing Conditions

The EFDC lake model was setup for a 2-year period from January 1, 2005 through December 31, 2006. Model results were calibrated and validated against observed data collected at 4 CDM/USGS water quality monitoring sites and 7 OWRB sites. Model results were calibrated to observations for water level, water temperature, TSS, nitrogen, phosphorus, dissolved oxygen, and algae biomass (chlorophyll-*a*). The model-data performance statistics selected for calibration of the hydrodynamic and water quality model are the Root Mean Square Error (RMSE) and the Relative RMS Error. The Relative RMS error, computed as the ratio of the RMSE to the observed range of each water quality constituent, is expressed as a percentage. The Relative RMS Error thus provides a straightforward performance measure statistic to evaluate agreement between model results and observations in comparison to model performance targets. This section provides a brief description of lake model calibration and validation. More details on the procedure used for EFDC model development and the results obtained for EFDC model calibration and validation are given in Appendix C of this report.

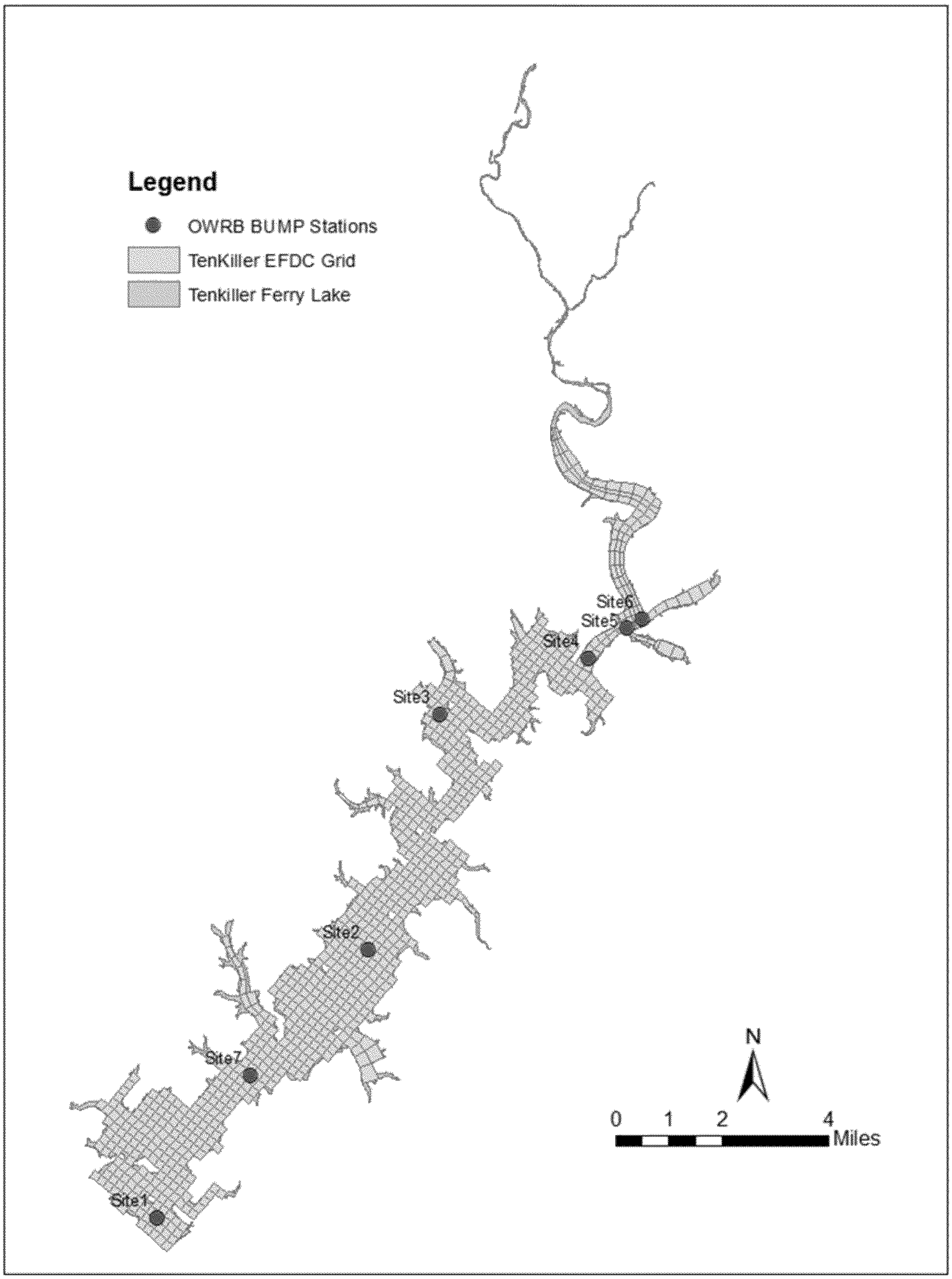


Figure 4.17 Location of OWRB BUMP Stations for Lake Model Calibration and Validation

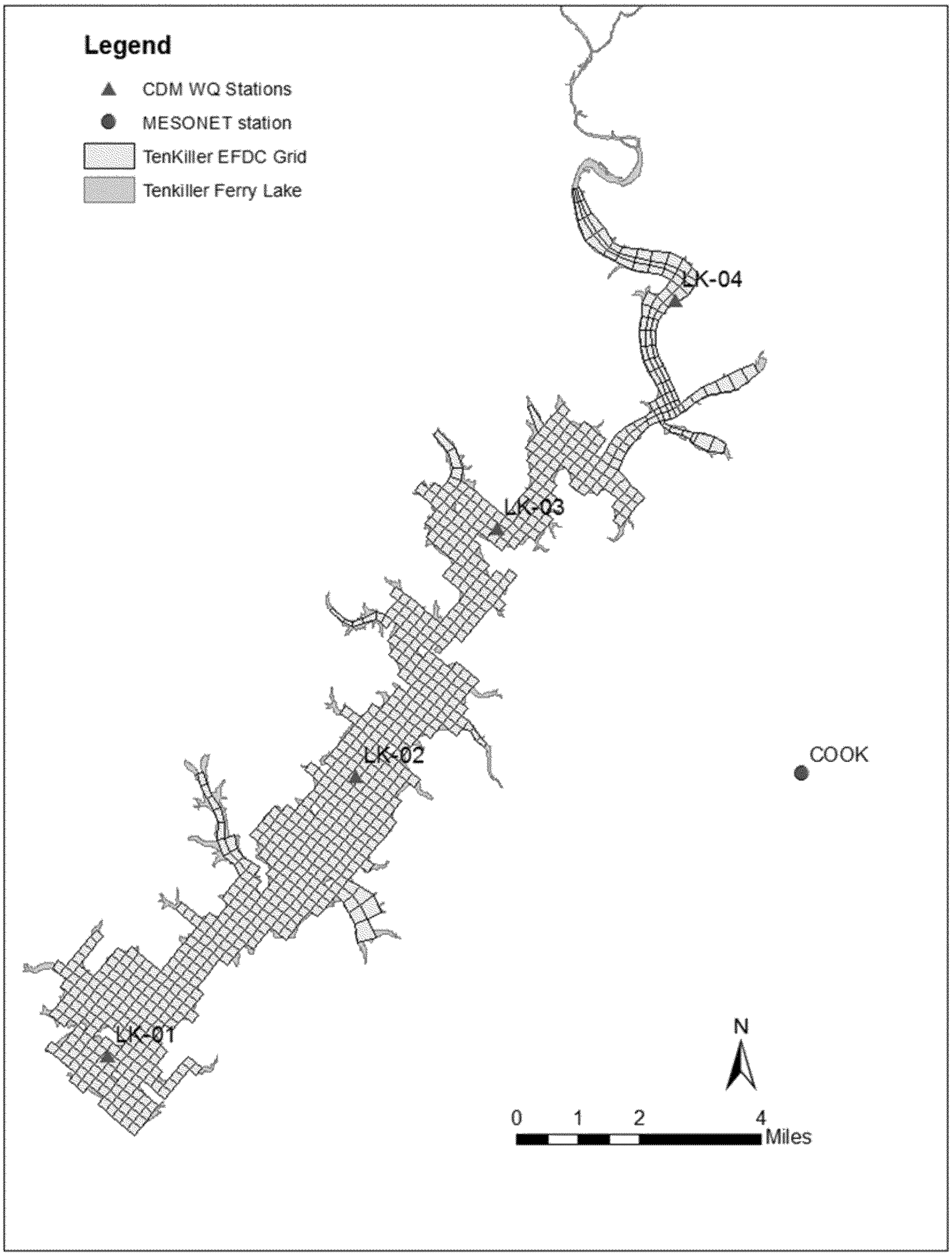


Figure 4.18 Location of the CDM/USGS Stations for Lake Model Calibration and Validation

Dissolved Oxygen. Proposed Oklahoma water quality standards for dissolved oxygen (OWRB, 2014) for Tenkiller Ferry Lake are specified as follows: 1) Surface DO shall not exhibit concentrations less than 6 mg/L in greater than 10% of the samples at early life stages (April 1 to June 15); 2) Surface DO shall not exhibit concentrations less than 5 mg/L in greater than 10% of the samples at other life stages including summer conditions (June 16 to October 15) and winter condition (October 16 to March 31); 3) Anoxic volume of the lake, defined by a DO target level of 2 mg/L, shall not exceed 50% of the lake volume based on volumetric data or 70% of the water column at any given sample site.

Model results for dissolved oxygen at sites in the lake show good agreement with the observed seasonal trend of both surface layer dissolved oxygen and bottom layer depletion of dissolved oxygen during stratified summer conditions. In the bottom layer, observed anoxic conditions during the summer months are controlled by the onset and erosion of lake stratification and decomposition of organic matter in the hypolimnion and the sediment bed. The model performance statistics for dissolved oxygen were good with a Relative RMS Error of 14.9% for the surface layer and 26.2% for the bottom layer at the forebay station LK-01. At all the validation stations, the performance for the surface and bottom layer results met or were close to the model performance target of 20% defined for the Relative RMS Error for dissolved oxygen.

Based on an assessment of water column dissolved oxygen data for the OWRB monitoring station near the dam (Site1), OWRB determined that Tenkiller Ferry Lake was not fully supporting its beneficial uses for Fish and Wildlife Propagation for a Warm Water Aquatic Community because dissolved oxygen data at this site showed that more than 70% of the water column was less than the 2 mg/L target for anoxia within the hypolimnion. As discussed in Section 2, vertical profiles of dissolved oxygen near the dam showed that more than 70% of the water column was less than the 2 mg/L target for anoxia within the hypolimnion for 2 of the sampling surveys from 1996-2010. The observed data used by OWRB for the 2010 303(d) list documents that the Warm Water Aquatic Community use for Fish and Wildlife Propagation was not attained because of depletion of dissolved oxygen in the hypolimnion of the deep waters of the lake near the dam.

Model results for dissolved oxygen are post-processed for selected sampling sites to derive time series data sets to compute the percentage of the water column defined as anoxic based on the cutoff target DO of 2 mg/L. Figure 4.19 and Figure 4.20 show model validation results for the percentage of the water column <2 mg/L in the deep part of the lake. As can be seen, the model results are in good agreement with the observed data for the OWRB Station Site1 and Site7. With a maximum of 77% of the water column <2 mg/L at Site1 and a maximum of 71% of the water column <2 mg/L at Site7, model validation results show violations of the 70% target for the water column in late July and August. In the transition zone (Site2, Site3, and Site4), the maximum anoxic percentage of the water column are all lower than 70%.

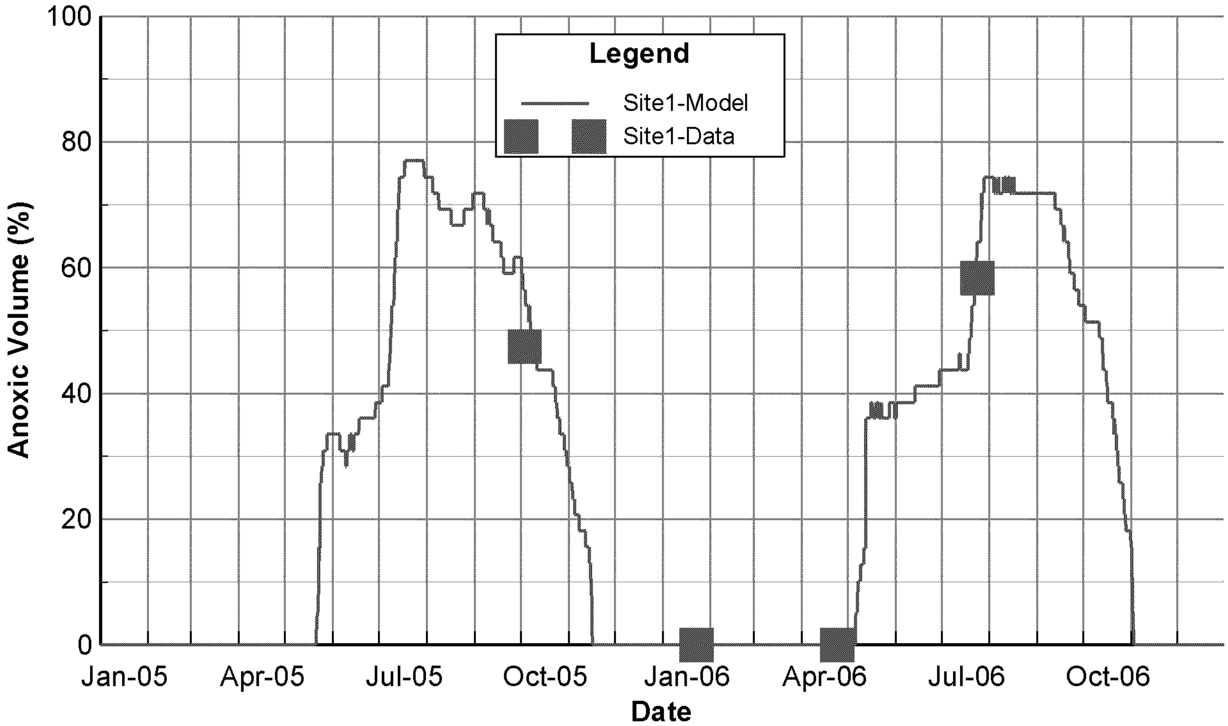


Figure 4.19 Model Validation for the Anoxic Water Column at OWRB Station Site1 Near the Dam.

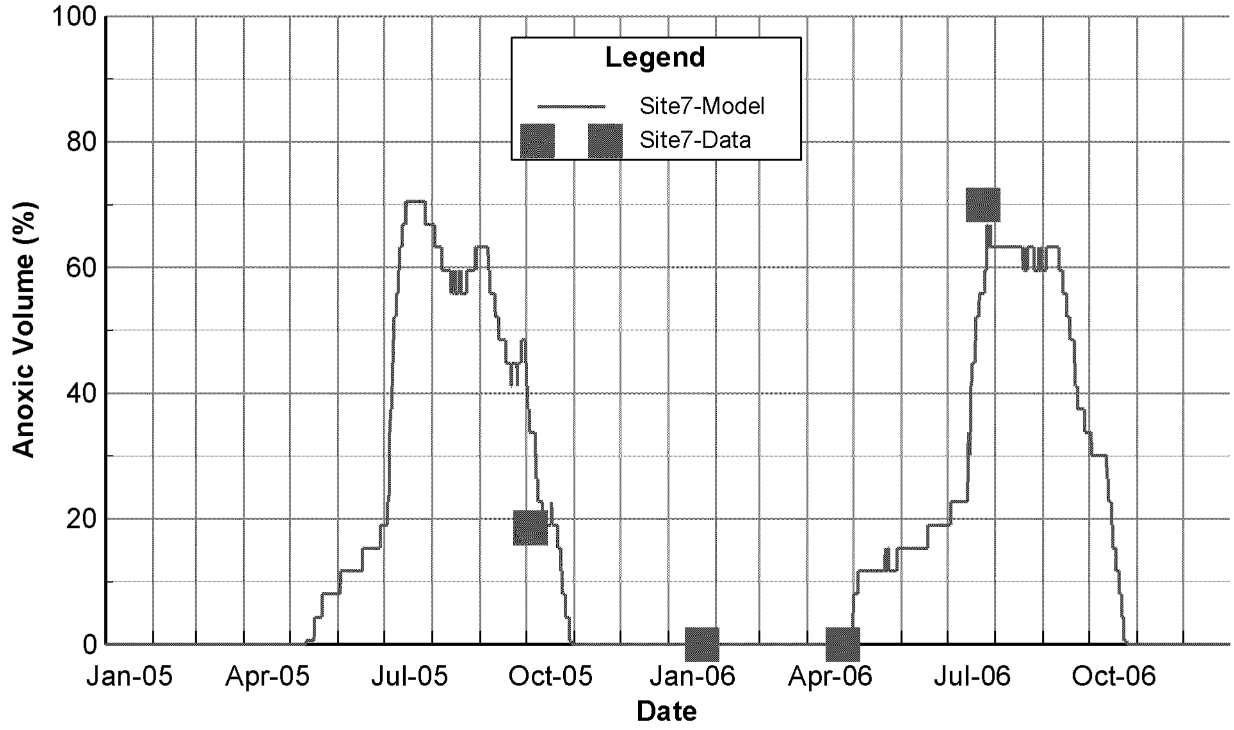


Figure 4.20 Model Validation for the Anoxic Water Column at OWRB Station Site7

Benthic Flux of Phosphate and Sediment Oxygen Demand. Model results for the validation year of 2005 are analyzed to evaluate benthic flux rates of phosphate and sediment oxygen demand (SOD) simulated with the sediment diagenesis model. These coupled water column-sediment bed processes provide a critical link with the lake model results obtained for nutrients, dissolved oxygen, and chlorophyll-*a*. As observed SOD are not available for Tenkiller Ferry Lake, modeled benthic fluxes for SOD are extracted for the stratified period defined for other life stages (June 16 to October 15) for CDM/USGS sites (LK-01, LK-02, LK-03, and LK-04). Simulated SOD are then compared to literature data from other lakes and reservoirs to assess how well the sediment flux model reproduces typical measured benthic flux rates. The mean modeled SOD rate (2.0 g/m^2-day), with a range of 0.2 – 3.8 g/m^2-day, is also consistent with the observed range of SOD rates measured in Wister Lake in Oklahoma (0.24 - 0.54 g O_2/m^2-day) (Haggard and Scott, 2011) and mesotrophic and eutrophic reservoirs in Texas and Oklahoma (1.7 - 4.1 g O_2/m^2-day) (Veenstra and Nolen, 1991).

Lasater and Haggard (2017) reported that the sediment P flux was 15.2 mg/m2-day in the riverine zone and 12.3 mg/m2-day in the transition zone in Tenkiller Lake based on field measurements made during the summer of 2016. EFDC simulated a peak sediment P flux in the riverine zone (LK-04) of 16.0 mg/m2-day which was close to the riverine zone results 15.2 mg/m2-day reported by Lasater and Haggard (2017). In the transition zone (LK-03), EFDC simulated a peak sediment P flux of 11.8 mg/m2-day which shows very good agreement with the measured flux of 12.3 mg/m2-day reported by Lasater and Haggard (2017). Cooke et al. (2011) used water column P observations for the riverine zone (LK-04) and the transition zone (LK-03) to derive an estimate of net internal P loading of 18.2 mg/m2-day for the stratified season from June-September during 2005-2006.

Sediment bed P in Tenkiller Lake, characterized by an increase over five decades from the 1950s to 2000, has decreased since 2002 (Haggard, 2010; Scott et al., 2011). Given the chronology of sediment bed P in the lake, the sediment P flux during 2005 to 2006 should be higher than, or close to, the sediment P flux rates measured by Lasater and Haggard (2017) in the summer of 2016. The estimate by Cooke et al. of net internal P loading of 18.2 mg/m2-day for summer 2005-2006 is, as suggested by the sediment bed P chronology, in fact higher than the in situ sediment P flux rates of 15.2 to 16.0 mg/m2-day measured by Lasater and Haggard (2017) in the summer of 2016. Considering the in situ sediment P flux measurements made in the summer of 2016 (Lasater and Haggard, 2017) and the estimates of internal loading rates for sediment P flux based on lake data for the summer months of 2005-2006 (Cooke et al., 2011), it is clear that the EFDC sediment flux model generated reasonable results for sediment P flux for summer stratified conditions at LK-03 in the transition zone and at LK-04 in the riverine zone.

Model-Data Performance. The Relative RMS Error performance of the lake model, defined as composite statistics derived from pooled model-observed data pairs for 2005-2006 for stations compiled in Appendix C, are consistent with model performance targets recommended for surface water models (Donigian, 2000). As presented in Appendix C, the model performance targets for dissolved oxygen (20%), water temperature (20%), TSS (100%), nutrients (50%) and chlorophyll (100%) are all attained with the model results for these state variables either better than, or close to, the target criteria for model performance.

Given the lack of a general consensus for defining quantitative model performance criteria, the inherent errors in input and observed data, and the approximate nature of model formulations, *absolute* criteria for model acceptance or rejection are not appropriate for studies such as the development of the model for Tenkiller Ferry Lake. The Relative RMS Errors are used as targets for performance evaluation of the calibration and validation of the lake model, but not as rigid absolute criteria for rejection or acceptance of model results. The “weight of evidence” approach used in this study recognizes that, as an approximation of a waterbody, perfect agreement between observed data and model results is not expected and is not specified as performance criteria for defining the success of model calibration. Model performance statistics are used as guidelines to supplement the visual evaluation of model-data plots for model calibration. The “weight of evidence” approach used for this study thus acknowledges the approximate nature of the model and the inherent uncertainty in both input data and observed data.

4.2.4 Pollutant Loads for Existing Model Calibration

Using data developed for validation of the watershed model and the lake model to 2005 conditions, mass loads for nutrients are compiled to identify the relative magnitude of the external and internal sources of pollutant loading to the lake. External sources include watershed tributary and overland runoff inputs and wet and dry atmospheric deposition. Internal sources include the benthic fluxes of inorganic nutrients across the sediment-water interface of the lake. Loading rates (as kg/day) are compiled for the 365 day simulation period from January to December 2005.

Table 4.19 presents a summary of nutrient and organic carbon loads for the existing 2005 validation conditions for HSPF watershed loads. The table presents a summary, and comparison, of sources from the watershed and atmospheric deposition and internal benthic flux loading rates for the existing 2005 validation conditions.

Table 4.20 presents the percentage contributions of watershed, atmospheric deposition and benthic flux loading to the total loads. As shown in **Table 4.20**, the internal benthic flux of total phosphorus accounts for 18.7% of the total phosphorus loading to the lake on an annual basis while external loading of phosphorus from the watershed accounts for 81.2%. The load budget for total nitrogen is dominated by loading from the watershed and the internal benthic flux of nitrogen is a sink of nitrogen from the watershed. Atmospheric deposition of both phosphorus and nitrogen accounts for only minor contributions to the total loading to the lake.

Table 4.19 Annual Loading from Watershed, Atmospheric Deposition and Sediment Flux of Nutrients, and TOC for Existing Validation Conditions (2005) Delivered to Tenkiller Ferry Lake

Model Validation, 2005	Annual	Annual	Annual	Annual
Source	**HSPF**	**AtmDep**	**SedFlux**	**Total**
Water Quality Parameter	**kg/day**	**kg/day**	**kg/day**	**kg/day**
Total Nitrogen (TN)	7572.0	61.56	-740.48	6893.1
Total Phosphorus (TP)	406.6	0.49	93.53	500.6
Total Organic Carbon (TOC)	6924.0	0.00	0.00	6924.0

Table 4.20 Percentage Contribution of Annual Loading from Watershed, Atmospheric Deposition, Sediment Flux of Nutrients, and TOC for Existing Validation Conditions (2005)

Model Validation, 2005	Annual	Annual	Annual	Annual
Source	**HSPF**	**AtmDep**	**SedFlux**	**Total**
Water Quality Parameter	**%**	**%**	**%**	**%**
Total Nitrogen (TN)	109.8%	0.9%	-10.7%	100%
Total Phosphorus (TP)	81.2%	0.1%	18.7%	100%
Total Organic Carbon (TOC)	100.00%	0.00%	0.00%	100.0%

4.2.5 Water Quality Response to Modeled Load Reduction Scenarios

The validated lake model was used to evaluate the water quality response to reductions in watershed loading of sediment and nutrients. Load reduction scenario “spin-up” simulation runs were performed to determine if water quality targets for chlorophyll-*a* and dissolved oxygen could be attained with watershed-based load reductions of 72%. The 72% removal scenario was used to simulate 8 years of sequential “spin-up” runs to evaluate the long-term response of water quality conditions in the lake to the 72% removal change in external loads from the watershed. For the set of spin-up runs, watershed flow and reduced pollutant loading from the HSPF model were repeated for each of the 8 spin-up years. The results derived from the 8 years of spin-up simulations did not, therefore, account for any projected, or future, conditions of hydrologic variability within the watershed.

Results of the spin-up model runs for the 72% removal scenario are presented to show long-term trends in chlorophyll-*a*, dissolved oxygen, benthic phosphate flux, and sediment oxygen demand. The spin-up results are also used to evaluate long-term changes in the relative contribution of internal phosphate loading from the sediment bed to external phosphate loads from the watershed and atmospheric deposition.

Chlorophyll-*a*. As discussed in Section 2 of this report, the Oklahoma water quality standard for chlorophyll-*a* is as follows:

- *Chlorophll-a*: the long-term average concentration of chlorophyll-*a* at a depth of 0.5 meters below the surface shall not exceed 0.010 milligrams per liter

summarizes annual statistics for surface layer chlorophyll-*a* for (a) the validated model results and the results generated with (b) eight years of spin-up runs for the 72% removal scenario, respectively. Summary statistics are computed from model results extracted for 4 OWRB stations (Site3, Site4, Site5, and Site6) located in the Illinois River Arm of Tenkiller Ferry Lake. Statistics are computed for the annual simulation period from January 2005 to December 2005. The chlorophyll-*a* statistics are given in Figure 4.21.

Table 4.21 Summary Statistics for Surface Layer Chlorophyll-*a*: Observations (2005), Model Validation and 8 Years Spin-Up of the 72% Removal Scenario. Target for chlorophyll a is lower than 10 µg/L Based on Annual Data.

Chlorophyll-*a* (µg/L), **Illinois River Arm, TENKILLER FERRY** LAKE	**ANNUAL**	
Site3, Site4, Site5, Site6	N_OBS	MEAN
OBS DATA	13	16.1
VALIDATION 2005	11680	15.3
YR0	11680	7.5
YR2	11680	6.2
YR4	11680	5.9
YR6	11680	5.7
YR8	11676	5.7

For the model validation year of 2005, the average value of observed chlorophyll-*a* (16.1 µg/L) and simulated chlorophyll-*a* (15.3 µg/L) in Tenkiller Ferry Lake showed violation of the water quality target of 10 µg/L. Figure 4.22 presents the simulated long-term trend of the average value of annual turbidity based on 8 years of simulated spin-up results. The load reduction scenario results in ~63% decrease of the average value of annual chlorophyll-*a* (from 15.3 to 5.7 µg/L) in the Illinois River Arm of the lake.

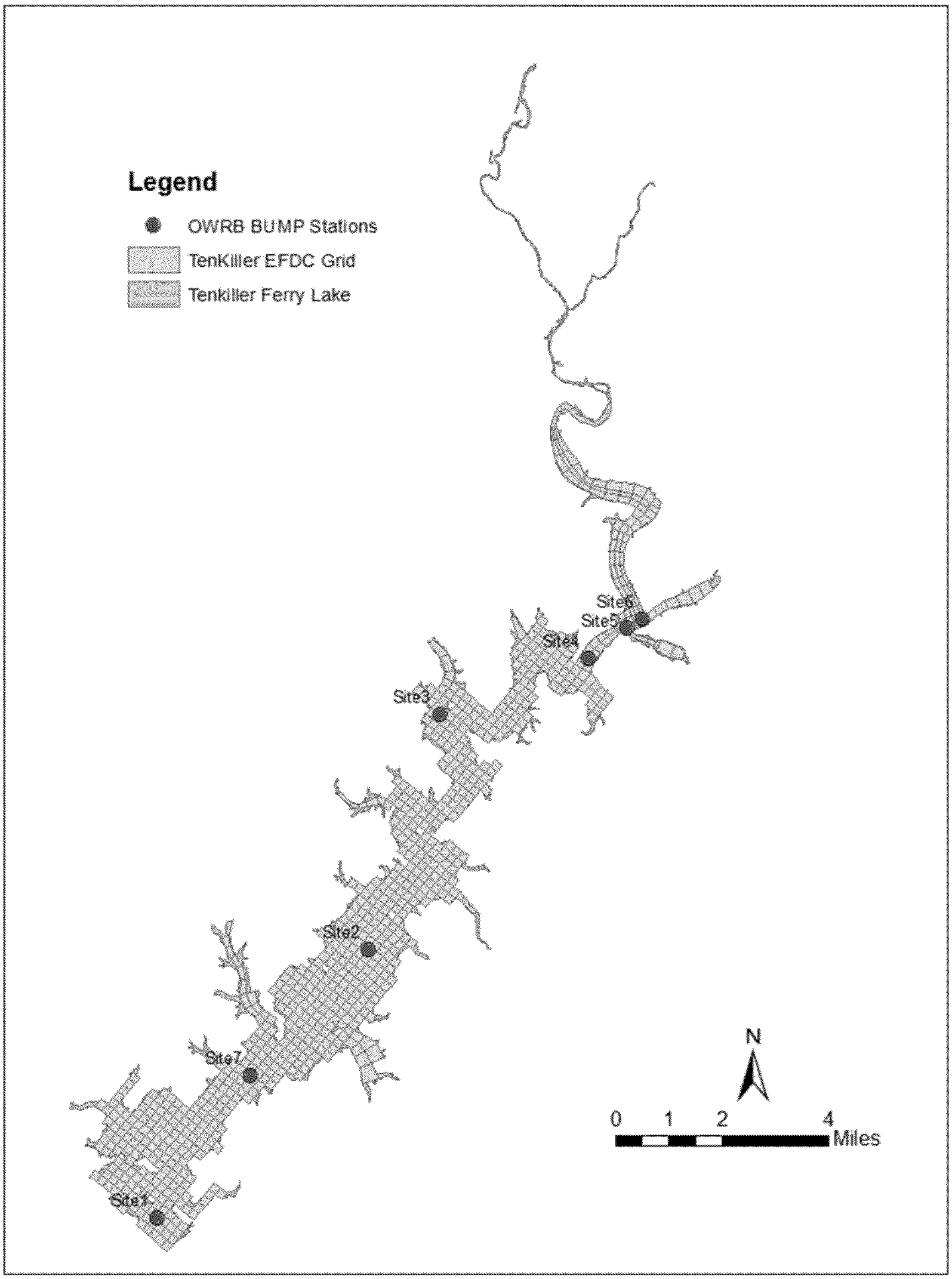


Figure 4.21 Locations of the OWRB Observed Stations in Illinois River Arm of Tenkiller Ferry Lake

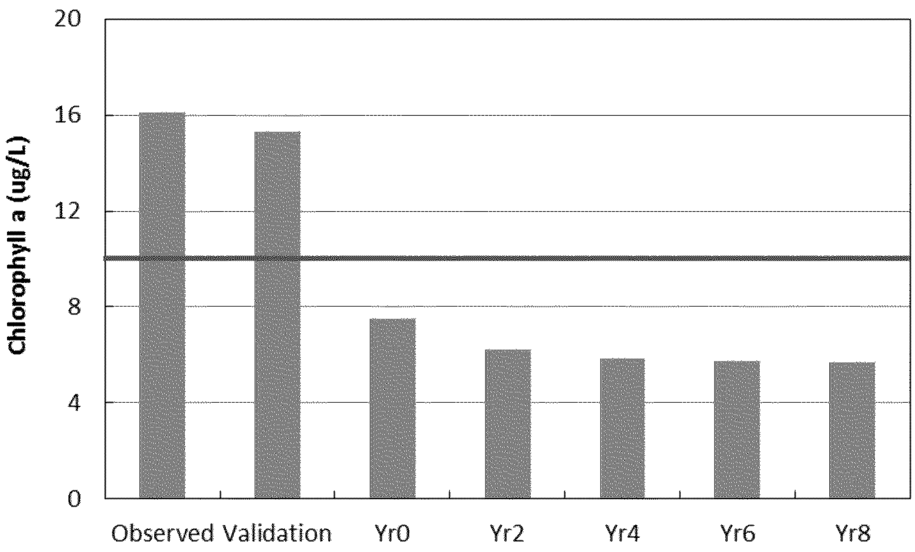


Figure 4.22 Chlorophyll-*a*, Average: Surface Observations (2005), Model Validation and 8 Years Spin-Up of the 72% Removal Scenario.

The spin-up simulation analysis of the coupled water column-sediment bed response to the 72% reduction in watershed and wastewater loading of nutrients indicates that compliance with the water quality criteria for chlorophyll-*a* of 10 µg/L can be attained in the Illinois River Arm of the lake within a reasonable time frame. **It is important to emphasize that the model spin-up results are <u>not</u> a prediction of the number of years required for lake recovery because of the idealized spin-up conditions of a precisely maintained watershed and wastewater discharge load reduction level and repeated climatic and hydrologic conditions of 2005.** The model results, do, however, provide technically credible evidence that future conditions can be in compliance with water quality targets for chlorophyll-*a* within a reasonable time frame if watershed loads are reduced as recommended and the reduction is sustained.

<u>Dissolved Oxygen</u>. The recently revised Oklahoma water quality standards for dissolved oxygen (OWRB, 2016) for Tenkiller Ferry Lake are specified as follows: 1) Surface DO shall not exhibit concentrations less than 6 mg/L in greater than 10% of the samples at early life stages (April 1 to June 15); 2). Surface DO shall not exhibit concentrations less than 5 mg/L in greater than 10% of the samples at other life stages including summer conditions (June 16 to October 15) and winter condition (October 16 to March 31); 3) Anoxic volume of the lake, defined by a DO target level of 2 mg/L, shall not exceed 50% of the lake volume based on volumetric data or 70% of the water column at any given sample site. Each criterion was checked to see whether the spin-up runs meet the TMDL DO targets or not.

<u>Early life stages (April 1 to June 15)</u>, 10th percentile value for surface DO is used for comparison to the water quality target of 6 mg/L since the water quality criteria state that no more than 10% of the samples are allowed to be lower than 6 mg/L.

Table 4.22 summarizes annual statistics for surface dissolved oxygen for (a) the validated model results and the results generated with (b) eight years of spin-up runs for the 72% removal scenario, respectively. Summary statistics are computed from model results extracted

for seven OWRB sites located within Tenkiller Ferry Lake. Statistics are computed for the simulation period from April 1 2005 to June 15 2005. The dissolved oxygen statistics are as shown in Figure 4.23.

For the model validation year of 2005, the 10th percentile of observed surface dissolved oxygen was 7.6 mg/L, indicating a compliance of the water quality standard of 6 mg/L. However, it must be pointed out that the sample size (n=7) is too small to generate a meaningful statistics. The sample size for the EFDC results for dissolved oxygen is 4,256 (3-hour interval), which is much more robust to represent the overall condition of the early life stages. The average of the 10th percentile of modeled surface dissolved oxygen at these seven OWRB stations during the early life stages for the validation model was 8.4 mg/L, indicating compliance with the water quality standard. For the spin-up years, the average of the 10th percentile of modeled surface dissolved oxygen seemed to be relatively constant around 8.5 mg/L, as shown in **Table 4.22** and Figure 4.24.

Table 4.22 Summary Statistics for Dissolved Oxygen, Surface: Observations (2005), Model Validation and 8 Years Spin-Up of the 72% Removal Scenario. Early Life Stage (April 1- June 15) for Tenkiller Ferry Lake.

DO (MG/L), LAKE Tenkiller	ANNUAL								
Site1, Site2, Site3, Site4, Site5, Site6, and Site7	N_OBS	MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MaX
OBS DATA	7	7.9	7.3	7.6	7.8	7.9	8.1	8.2	8.2
VALIDATION 2005	4256	9.2	7.8	8.4	8.6	9.0	9.6	10.3	13.4
YR0	4256	9.1	7.9	8.3	8.6	9.0	9.5	10.2	10.9
YR2	4256	9.3	8.0	8.5	8.7	9.2	9.6	10.3	11.0
YR4	4256	9.3	8.0	8.5	8.8	9.2	9.6	10.3	11.0
YR6	4256	9.3	8.0	8.5	8.8	9.2	9.6	10.3	11.0
YR8	4256	9.3	8.0	8.5	8.8	9.2	9.6	10.3	11.0

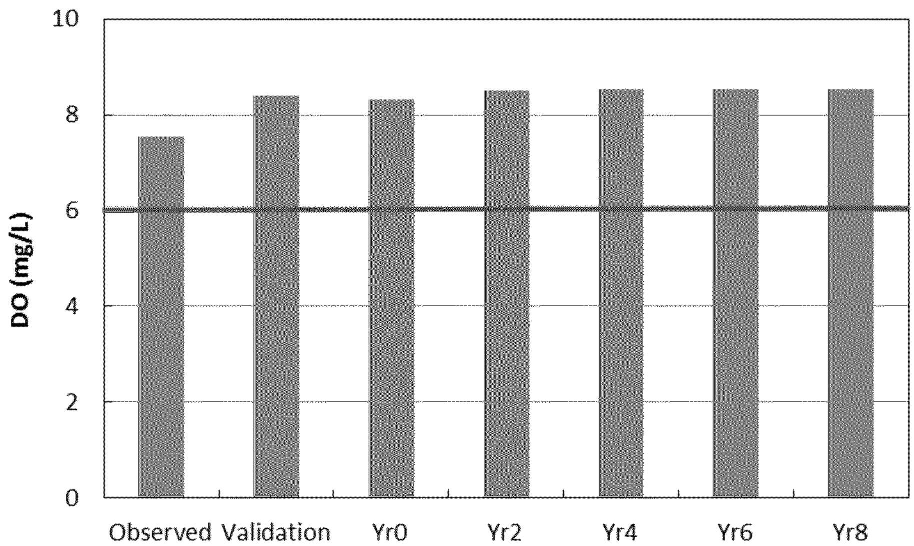


Figure 4.23 Dissolved Oxygen, Surface, 10th percentile: Observations (2005), Model Validation and 8 Years Spin-Up of the 72% Removal Scenario. Early Life Stage (April 1-June 15) for Tenkiller Ferry Lake.

Other life stages including summer conditions (June 16 to October 15) and winter condition (October 16 to March 31). The 10th percentile value for surface DO is used for comparison to the water quality target of 5 mg/L since the water quality criteria states that no more than 10% of the samples are allowed to be lower than 5 mg/L.

Table 4.23 summarizes annual statistics for surface dissolved oxygen for (a) the validated model results and the results generated with (b) eight years of spin-up runs for the 72% removal scenario, respectively. Summary statistics are computed from model results extracted for 7 OWRB sites located in Tenkiller Ferry Lake. Statistics are computed for the simulation period of other life stages (summer and winter conditions). The dissolved oxygen statistics are shown in Figure 4.24.

For the model validation year of 2005, the 10th percentile of observed surface dissolved oxygen was 7.5 mg/L, indicating compliance with the water quality standard at other life stages even though the sample size (n=21) is small. The validation model and spin-up runs also confirmed compliance for the water quality standard for dissolved oxygen at other life stages.

Table 4.23 Summary Statistics for Dissolved Oxygen: Surface Observations (2005), Model Validation and 8 Years Spin-Up of the 72% Removal Scenario. Other Life Stages (summer and winter conditions) for Tenkiller Ferry Lake.

DO (MG/L), LAKE Tenkiller	ANNUAL								
Site1, Site2, Site3, Site4, Site5, Site6, and Site7	N_OBS	MEAN	MIN	10Pct	25Pct	50Pct	75Pct	90Pct	MaX

OBS DATA	21	9.4	7.4	7.5	8.1	8.4	11.6	12.1	13.0
VALIDATION 2005	16184	9.4	6.4	7.5	7.9	9.1	10.9	11.3	11.9
YR0	16184	9.3	6.4	7.4	7.7	8.8	10.9	11.3	12.0
YR2	16184	9.4	6.6	7.5	7.7	9.1	11.1	11.5	12.1
YR4	16184	9.5	6.9	7.6	7.8	9.2	11.1	11.5	12.2
YR6	16184	9.5	7.0	7.6	7.8	9.2	11.2	11.6	12.2
YR8	16184	9.6	7.0	7.6	7.8	9.2	11.2	11.6	12.2

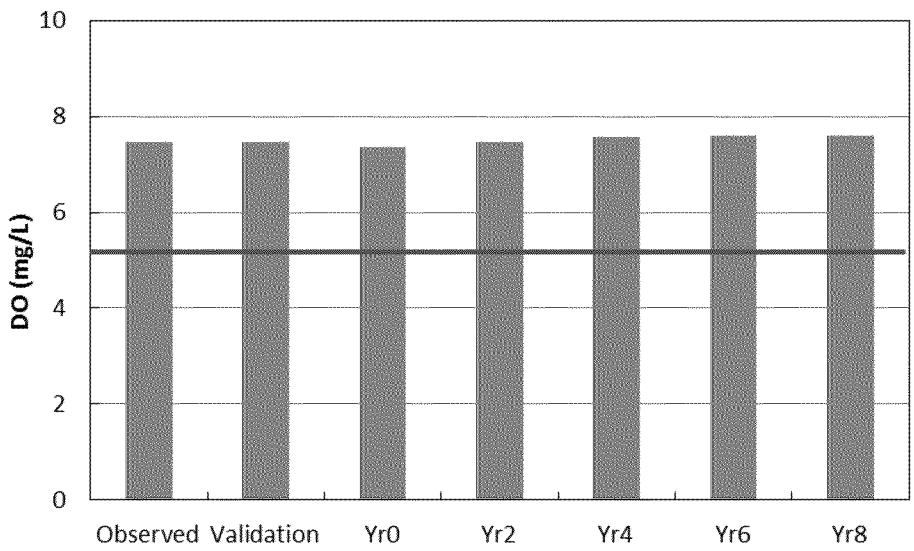


Figure 4.24 Dissolved Oxygen, Surface: 10th percentile Observations (2005), Model Validation and 8 Years Spin-Up of the 72% Removal Scenario. Other Life Stages (summer and winter conditions) for Tenkiller Ferry Lake.

Anoxic Water Column. Anoxic volume of the lake, defined by a DO target level of 2 mg/L, shall not exceed 50% of the lake volume based on volumetric data or 70% of the water column at any given sample site. The revised water quality criteria for dissolved oxygen require that, on a volumetric basis, 50% or less of the whole lake volume must be lower than a 2 mg/L cutoff concentration for DO. The revised criteria also indicate that no more than 70% of the DO measurements in a water column profile at a sampling site can be less than 2 mg/L (OWRB, 2014).

Time series of the model results for the anoxic water column are extracted for the OWRB Site1 and Site7, the deep area of the lake. As can be seen in Figure 4.25 and Figure 4.26 for model validation, the model results for the percentage of the water column <2 mg/L are in good agreement with observations at Site1 and Site7. Although observed data are not available for confirmation, the model results indicate that a maximum of 77% of the water column is <2 mg/L in late July at Site1 and a maximum of 71% of the water column is <2 mg/L in late July and early August at Site7.

If spin-up of the load reduction scenario succeeds in decreasing the peak anoxic percentage of the water column to less than 70% then compliance with the criteria for water column dissolved oxygen at a sampling site will be attained. Figure 4.25 and Figure 4.26 present time series results for model validation and spin-up of the 72% removal scenario for every other year at Site1 and Site7, respectively.

As can be seen by comparison of the model validation results to the spin-up results after 8 years, the peak anoxic percentage in late July at Site1 is seen to decrease from 77% for the existing conditions to less than 70% for the 72% removal scenario after Y2. The peak anoxic percentage in late July and early August at Site7 is seen to decrease from 71% for the existing conditions to less than 70% for the 72% removal scenario after Y0.

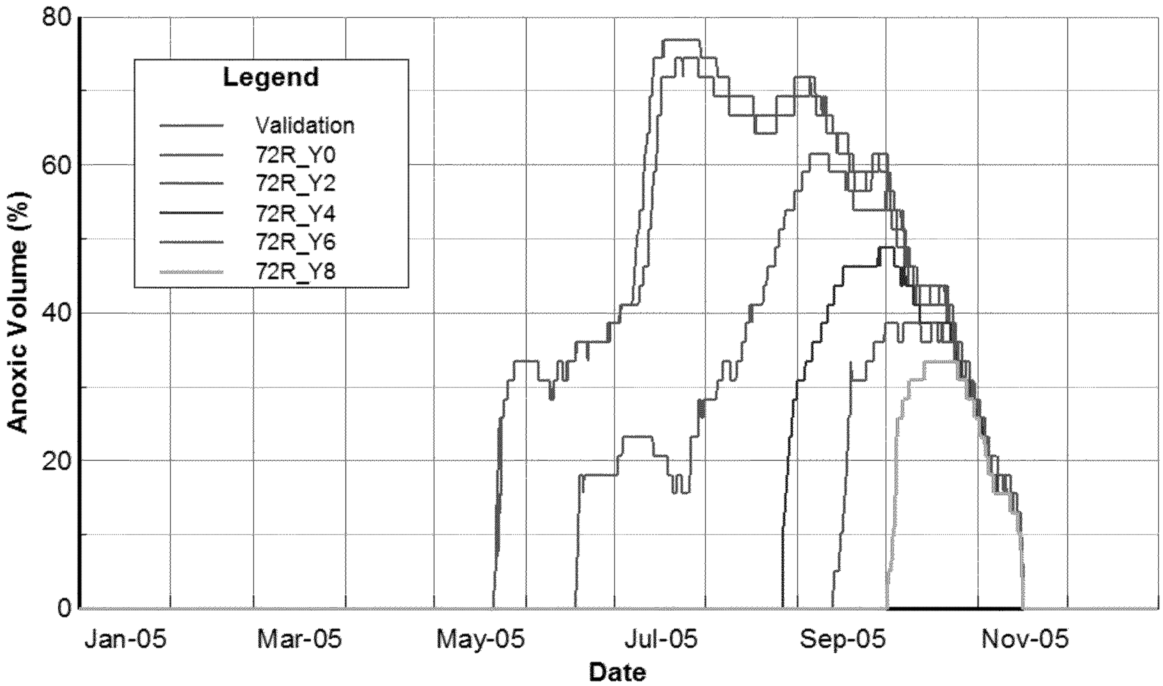


Figure 4.25 Time Series of Anoxic Water Column for Selected Spin-up Years of the 72% Removal Scenario at Site 1. Model validation results are shown as red line. Percentage of anoxic water column is based on extraction of grid cell model results for OWRB Station Site1 near the dam. DO cutoff target is 2 mg/L.

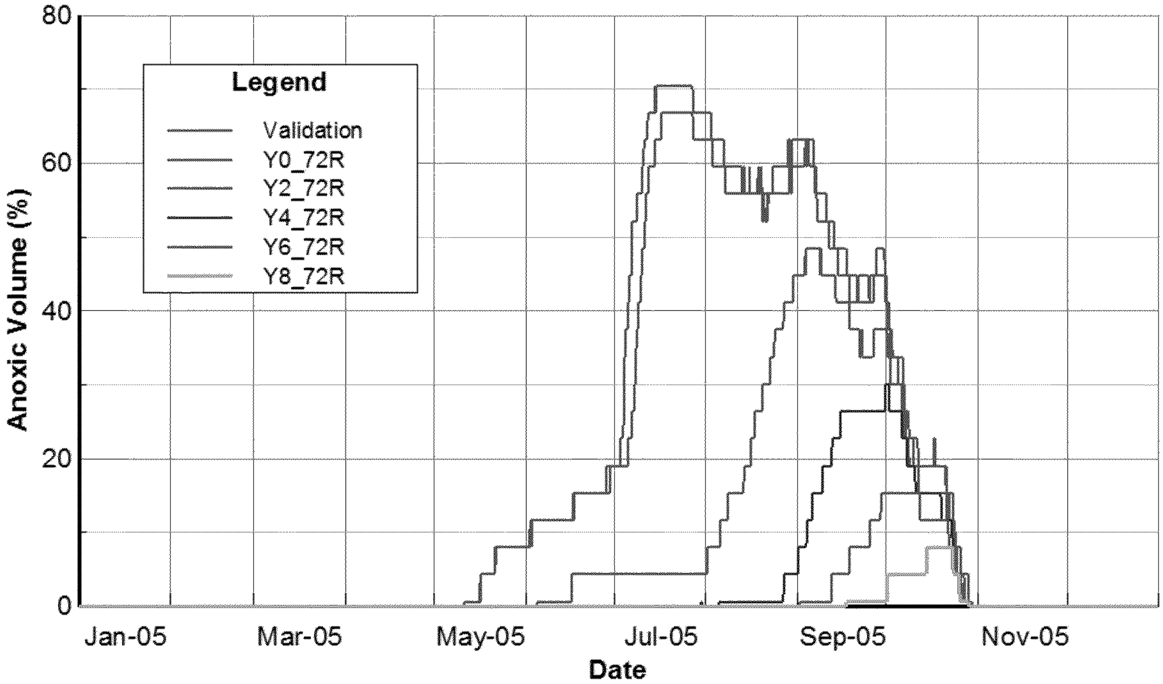


Figure 4.26 Time Series of Anoxic Water Column for Selected Spin-up Years of the 72% Removal Scenario at Site 7. Model validation results are shown as red line. Percentage of anoxic water column is based on extraction of grid cell model results for OWRB Station Site7. DO cutoff target is 2 mg/L.

Sediment Oxygen Demand (SOD). The sediment oxygen demand rate showed a decreasing trend over the spin-up years. As shown in **Figure 4.27**, average SOD based on model results for Site1, Site2, Site3, Site4, Site5, Site6, and Site7 decreases from 1.48 g O_2/m^2-day for the existing validation conditions to 0.46 g O_2/m^2-day after 8 years of model spin-up.

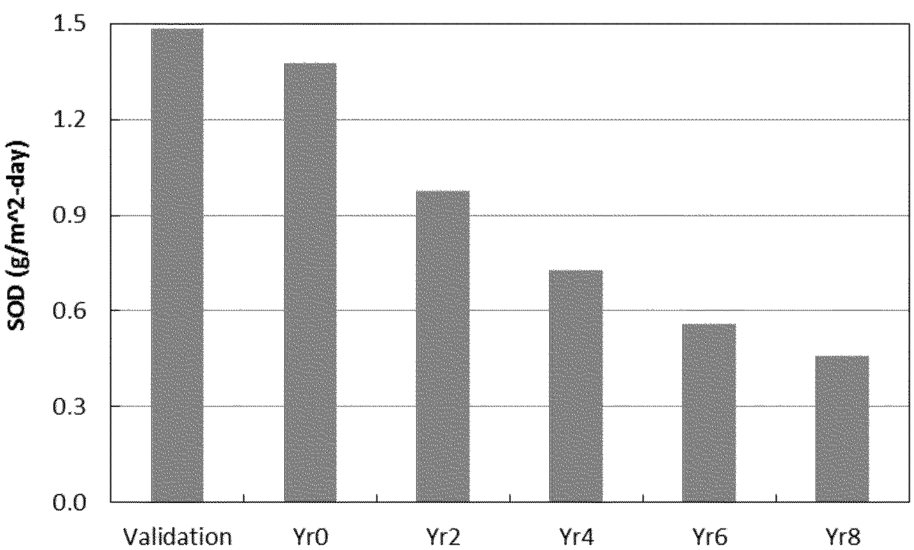


Figure 4.27 Sediment Oxygen Demand (g O2/m2-day). Spin-Up Model Results for 72% Removal, Average of Site1, Site2, Site3, Site4, Site5, Site6, and Site7.

As demonstrated with the analysis of model results for the spin-up years, the 72% reduction of nutrients and sediment loads determined for the TMDL is expected to result in compliance with Oklahoma water quality criteria for surface layer dissolved oxygen at both early and other life stages. The 72% reduction scenario also results in improvement of the anoxic conditions at the deep water Site1 near the dam and Site7 with the peak anoxic percentage of the water column shown to be less than the 70% target.

4.2.6 Pollutant Loads for Removal Scenario

The water quality targets for the load reduction analysis are the conservative assumptions adopted for the more stringent water quality standards for chlorophyll-*a* and dissolved oxygen. A water quality target for nutrients is not explicitly specified for the TMDL analysis because targets are only designated for the water quality constituents that are directly linked to impairments.

The 72% load reduction determined for the load allocation analysis was assigned a reduction of 72% for the nonpoint loading from HSPF watershed inflows to the lake. The 72% load reductions for TN, TP, and TOC are determined from existing conditions loads (2005) as follows:

- The LA reduction for watershed nonpoint loading is computed from the existing watershed nonpoint loading x (1-72% Reduction).
- There is no LA assigned for the sediment flux of nutrients since this is an internal response to external reductions for LA for watershed inflow to the lake. The decreased load shown for sediment flux loading is computed internally in the EFDC lake model as the modeled response of the sediment bed for nutrient flux to the 72% reduction in external (LA) source loading.
- There is no LA reduction for atmospheric deposition of nutrients since this is considered to be an uncontrollable source.

Table 4.24 presents a summary of the January 2005-December 2005 loads for the 72% removal scenario for HSPF watershed loads, and comparison, of the external sources and internal benthic flux loading rates for the 72% removal scenario.

As shown in **Table 4.24** and**Table 4.25**, the TP contribution percentage from the internal sediment flux (19.9%) is much higher than the TN contribution percentage from the internal sediment flux (-0.4%). In addition, the TP contribution percentage from the internal sediment flux (19.9%) is significantly lower than that from the watershed loadings (79.9%). The nutrient contributions from atmospheric deposition are minor compared with the other sources.

Table 4.24 Annual Loading of Nutrients and Sediment from Watershed, Atmospheric Deposition, and Internal Sediment Flux for 72% Removal Scenario Delivered to Tenkiller Ferry Lake.

Model Validation	Annual	Annual	Annual	Annual
Source	HSPF	AtmDep	SedFlux	Total
72% Reduction at Year 8	kg/day	kg/day	kg/day	kg/day

Total Nitrogen (TN)	2211.3	61.56	-9.55	2263.3
Nitrate (NO3)	1820.4	23.87	-144.36	1700.0
Ammonia (NH4)	44.2	37.69	134.81	216.7
Total _OrgN	342.7	0.00	0.00	342.7
DIN (NO3+NH4)	1864.6	61.56	-9.55	1916.7
Total Phosphorus (TP)	140.9	0.49	35.02	176.4
Phosphate (PO4)	88.7	0.49	35.02	124.2
Total_OrgP	51.7	0.00	0.00	51.7
Total Organic Carbon (TOC)	2253.7	0.00	0.00	2253.7

Table 4.25 Percentage Contribution of Annual Loading of Nutrients and Sediment from Watershed, Atmospheric Deposition, and Internal Sediment Flux for 72% Removal Scenario.

Model Validation	Annual	Annual	Annual	Annual
Source	HSPF	AtmDep	SedFlux	Total
72% Reduction at Year 8	%	%	%	%
Total Nitrogen (TN)	97.7%	2.7%	-0.4%	100%
Nitrate (NO3)	107.1%	1.4%	-8.5%	100%
Ammonia (NH4)	20.4%	17.4%	62.2%	100%
Total _OrgN	100.0%	0.0%	0.0%	100%
DIN (NO3+NH4)	97.3%	3.2%	-0.5%	100%
Total Phosphorus (TP)	79.9%	0.3%	19.9%	100%
Phosphate (PO4)	71.4%	0.4%	28.2%	100%
Total_OrgP	100.0%	0.0%	0.0%	100%
Total Organic Carbon (TOC)	100.0%	0.0%	0.0%	100%

4.2.7 Summary

The EFDC lake model incorporates watershed loading and internal coupling of organic matter deposition to the sediment bed with decomposition processes in the bed that, in turn, produce benthic fluxes of nutrients and sediment oxygen demand across the sediment-water interface. Tenkiller Ferry Lake, like many reservoirs, is characterized by seasonal thermal stratification and hypolimnetic anoxia. Summer anoxic conditions, in turn, are associated with internal nutrient loading from the benthic release of phosphate and ammonia into the water column that is triggered, in part, by low dissolved oxygen conditions in the hypolimnion. The mass balance based model, validated to 2005 data, accounts for the cause-effect interactions of water clarity, nutrient loading, nutrient cycling, algal production, particulate organic matter deposition, decay of organic matter in the sediment bed, and internally generated sediment-water fluxes of nutrients and dissolved oxygen.

The model indicates that water quality conditions are expected to be in compliance with the water quality criteria for chlorophyll-*a* of 10 µg/L in the Illinois River Arm of the lake within a reasonable timeframe. It is important to note, however, that the spin-up results for the 72% removal scenario should not be taken as absolute projections of future water quality conditions in the lake with certainty as to some future calendar date. The model results reflect the idealized spin-up conditions of a precisely maintained watershed load reduction level and repeated climatic conditions of the hydrologic conditions of 2005. The model, does however, provide a technically credible framework that clearly shows that water quality improvements can be achieved in Tenkiller Ferry Lake within a reasonable time frame to support the desired beneficial uses if watershed loading can be controlled and sustained to a level based on a 72% reduction of the existing loading conditions for nutrients, and organic matter. Attainment of water quality standards will occur, however, only over a period of time and only after full implementation of NPDES point source controls and BMPs considered necessary to achieve an overall 72% removal of organic matter and nutrients from the watershed.

The model results suggest that compliance with water quality criteria for dissolved oxygen can be achieved with an overall 72% removal of nutrients from watershed loading to the lake within a reasonable time frame. The model results thus support the development of TMDLs for organic carbon, total nitrogen and total phosphorus to achieve compliance with water quality standards for chlorophyll-*a* and dissolved oxygen. The calibrated and validated watershed and lake model of Tenkiller Ferry Lake provides DEQ with a scientifically defensible surface water model framework to support determination of TMDLs and development of water quality management plans for Tenkiller Ferry Lake.

SECTION 5. TMDL ALLOCATIONS

The purpose of the Loading allocation is to develop the framework for reducing pollutant loading under the existing watershed conditions so that water quality standards can be met. The Loading Allocations (L represents the maximum amount of pollutant that the stream can receive without exceeding the water quality criteria. The load allocations for the selected scenarios were calculated using the following equation:

$$\text{Loading Allocation} = \Sigma\ \text{WLA} + \Sigma\ \text{LA} + \text{MOS}$$

Where,

WLA = waste load allocation (point source contributions);
LA = load allocation (non-point source contributions); and
MOS = margin of safety.

Typically, several potential allocation strategies would achieve the Loading Allocation endpoint and water quality standards. Available control options depend on the number, location, and characteristics of the pollutant sources.

For the IRW, the Loading Allocation that would meet the Scenic River instream criteria for TP was determined through a series of model executions for alternative scenarios to ultimately arrive at the recommended Final TMDL scenario that would meet the TP criteria, of 0.037 mg/l TP, as a 30-day geomean of daily concentrations. These analyses were performed at both the AR/OK stateline (defined as the USGS gage 07195430 South of Siloam Springs and represented by Reach 630 in the Watershed Model), and the final Illinois River reach (Reach 890) draining to, and providing loadings to Tenkiller Ferry Lake.

In order to prepare for, and set the foundation for, the scenario analyses, the calibrated watershed model must first be revised to represent our best assessment of 'current' or Baseline conditions. This provides the 'starting point' to which the alternative scenarios are compared. As noted above, the IRW model was calibrated to data for the period of 2001 to 2009, using land use conditions, actual effluent discharges for the permitted point sources, litter application rates, fertilizer applications rates, atmospheric deposition, etc., all appropriate for that specific time period. Thus the results of the calibration runs are specific to the time period of the calibration, 2001 – 2009. For the Baseline run, we imposed a number of differences to approximate 'current' conditions on the watershed, for the general time period of about 2009-2015 to which alternative scenarios could be compared.

The specific differences between the calibration condition and the Baseline condition are as follows:

- The Baseline model time span is 1992-2009, 18 years; whereas the calibration span was 2001-2009.
- The Baseline run point sources are monthly values from 2015 (distributed to daily inputs) that are applied to each year of the run; we processed data that EPA Region 6 provided for the simulation.
- The Baseline land use is NLCD 2011 as opposed to the NLCD 2006 used in the calibration.

- Both runs have the baseflow added to RCHs 150, 304, 308 to account for low flow contributions from regional aquifers.
- Expert System/hydrology output (COPYs) has been removed from the Baseline run (does not impact the simulation results, just the time of execution).
- Litter application rates in the Baseline run are set to 2009 values for all years.
- Both runs have the updated monthly distribution for litter applications, and the updated 10% surface and 90% upper layer for litter applications.
- Both runs have updated RCHRES nitrification and denitrification rates and parameters developed by EPA Region 6.
- Both runs have same manure application rates, and the same N fertilizer added to non-litter pasture.
- Both runs have same remaining parameter values throughout.

The linked watershed (HSPF) and lake (EFDC) models were used to calculate average annual TOC, nitrogen and phosphorus loads (as kg/yr), that, if achieved, should meet the water quality targets established for chlorophyll-*a* and dissolved oxygen. For reporting purposes, the final TMDLs, according to EPA guidelines (Grumbles, 2006), are expressed for Tenkiller Ferry Lake as daily maximum loads (as kg/day).

5.1. Waste load allocation (WLA)

The waste load allocation for the TMDL for Tenkiller Ferry Lake will be assigned to regulated NPDES point source facilities that discharge to Tenkiller Ferry Lake as described below.

5.1.1 NPDES Municipal and Industrial Wastewater Facilities

5.1.2 NPDES Municipal Separate Storm Sewer System (MS4)

5.1.3 NPDES Construction Site Permits

5.1.4 NPDES Multi-Sector General Permits (MSGP) for Industrial Sites

5.1.5 NPDES Animal CAFOs

To represent the WLA loads in the IRW model, the point sources listed in Table 5.1 and included in the calibration were also included for the Baseline run using data from 2015 to generate the input loads, based on data provided by EPA Region 6. The only differences being the inclusion of the NACA facility, which came online in late 2009, and the closing of the Fayetteville-Nolan plant in 2007. Figure 5.1 shows the locations of the facilities listed in Table 5.1

Table 5.1 Annual Loads (lbs/yr) of TP, TN, and CBOD for 2015 used for Baseline Run and Scenarios

NPDES #	Facility	TP	TN	$CBOD_u$
AR0022098	Prairie Grove	783	10,999	8,772

AR0020010	Fayetteville - Noland (2007)	-	-	-
AR0050288	Fayetteville - Westside	3,210	178,768	35,865
AR0033910	USDA FS - Lake Wedington	3	138	67
AR0035246	Lincoln	439	12,609	5,528
AR0022063	Springdale	10,479	309,583	54,693
AR0043397	Rogers	4,525	199,983	28,688
AR0020184	Gentry	4,176	12,903	14,614
AR0020273	Siloam Springs	2,418	35,314	48,819
AR0037842	SWEPCO	-	-	-
OK0026964	Tahlequah	2,518	83,822	27,104
OK0028126	Westville	283	3,703	1,664
OK0030341	Stilwell	3,124	32,261	26,794
AR0050024	NACA	378	61,203	14,140

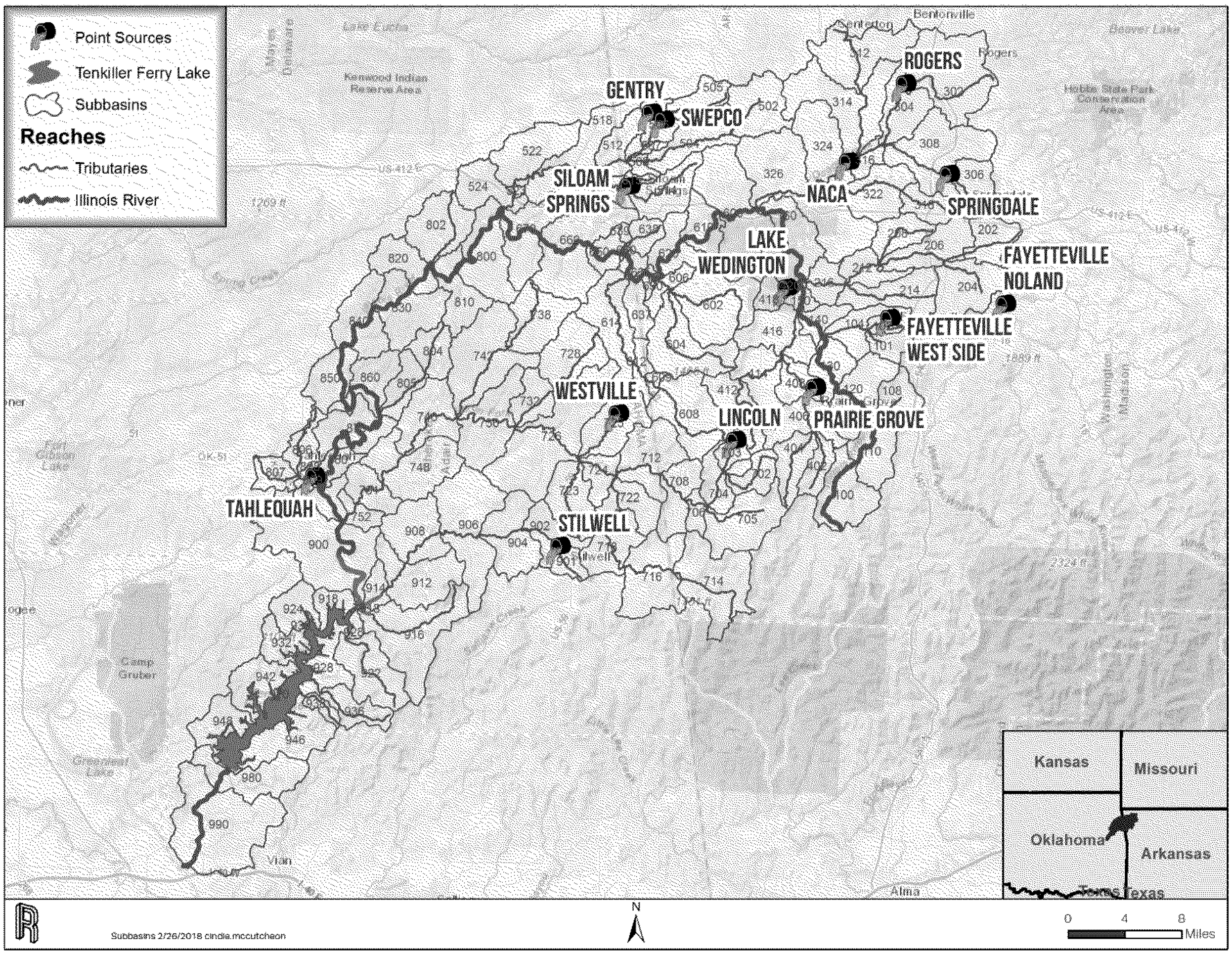


Figure 5.1 Locations of IRW Point Source Dischargers

5.2. Load Allocation (LA)

Nonpoint Sources

The Load Allocation for the TMDL for Tenkiller Ferry Lake will be based on the 72% reduction of watershed loads for nutrients derived from the watershed model loads developed for the existing conditions of 2005. The load allocation assigned for watershed runoff will be proportional to the watershed model's contribution to total external point and nonpoint source loading estimated for the 2005 model validation conditions (see Section 4.4).

5.3. Consideration of Critical Condition

EPA regulations, 40 CFR 130.7 (c)(1), require Loading Reduction to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the impaired streams is protected during times when it is most vulnerable. Critical conditions are important because they describe the combination of factors that cause an exceedance of water quality criteria. They will help in identifying the actions that may have to be undertaken to meet water quality standards.

To a great extent, watershed modeling eliminates the need to pre-define critical conditions for water quality standards violations as it includes and represents the dynamic impacts of both point and nonpoint sources, in conjunction with climatic and watershed characteristics that determine and control the water quality behavior of the watershed. Analysis of the timeseries of the predicted water quality concentrations of the model (daily or hourly) will show when and where in the watershed the water quality standard violations occur. Although low-flow conditions during late summer and fall are often the critical condition of concern for point-source dominated watersheds, this is not always the case in complex watersheds, like the IRW, where both point and nonpoint sources are present. Furthermore, the water quality timeseries can be analyzed to identify the frequency and duration of water quality violations at any point in the watershed, demonstrating the analytical power of the watershed modeling approach.

Insert a paragraph about Lake Modeling -DS

The model simulation period was selected to include both low flow and high flow conditions, thus covering all of the flow regimes. The long-term simulation of 18 years, 1992 to 2009, used in this Loading Reduction modeling study will guarantee that all critical conditions were addressed in the Loading Reduction.

5.4. Seasonal Variability

Federal regulations [40 CFR §130.7(c)(1)] require that TMDLs account for seasonal variability in watershed hydrologic conditions and pollutant loading. Seasonal variation was accounted for in the TMDL determination for Tenkiller Ferry Lake in two ways: (1) water quality standards, and (2) the time period represented by the watershed and lake models. As described in Section 2, Oklahoma's water quality standards for dissolved oxygen (recently revised by OWRB, 2016) for lakes are developed on a seasonal basis to be protective of fish and wildlife propagation for a warm water aquatic community at all life stages, including spawning. Within the surface layer, dissolved oxygen standards specify that the 10th percentile of DO levels shall be no less than 6 mg/L from April 1 to June 15 to be protective of early life stages. For the summer months from June 16 through October 15, the 10th percentile of surface DO shall be no less than 5 mg/L. For the fall-winter period from October 16-March 31, the 10th percentile DO shall be no less than 5 mg/L. In addition to criteria for the surface layer DO, the hypoxic volume of the lake, defined by a DO target of no less than 2 mg/L, is not to be greater than 50% of the lake volume on a volumetric basis or no greater than 70% of the water column at any given sample site.

Seasonality was also accounted for in the TMDL analysis by developing the models based on two years of water quality data collected in 2005-2006 as part of routine monitoring efforts initiated by the CDM/USGS in 2003 for Tenkiller Ferry Lake. As discussed in Section 1.3, flow and water quality data collected during 2005-2006 for this TMDL study is considered to be representative of dry and average hydrologic conditions. The watershed (HSPF) and lake (EFDC) models developed to support this TMDL study are both time variable models with results reported at hourly and daily intervals for the study period. The watershed model was used to simulate loads for a period from January 1992 throuhg December 2009, while the lake model was used from January 2005 through December 2006. The watershed and lake models thus included both hydrologic and limnological conditions over the full annual cycles of the four seasons.

5.5. Margin of Safety (MOS)

Federal regulations [40 CFR §130.7(c)(1)] require that TMDLs include a Margin of Safety (MOS). The MOS is a conservative measure incorporated into the TMDL determination that accounts for uncertainty and the lack of knowledge associated with calculating the allowable pollutant loading to ensure WQSs are attained. EPA guidance about the Margin of Safety for development of TMDLs states that: *A margin of safety expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL; e.g., derivation of numeric targets, modeling assumptions, or effectiveness of proposed management actions which ensures attainment and maintenance of water quality standards for the allocated pollutant [40 CFR 130.33(b)(7)].*

EPA guidance allows for use of either implicit or explicit expressions of the MOS, or both. When conservative assumptions are used in development of the TMDL, or conservative factors or assumptions are used in the TMDL analysis, the MOS is implicit. When a specific percentage of the TMDL is set aside to account for the lack of knowledge, then the MOS is considered explicit and the MOS quantifies an allocation amount separate from other load and wasteload allocations.

The margin of safety (MOS) is a required component of the TMDL to account for any lack of knowledge concerning the relationship between effluent limitations and water quality. According to EPA guidance (USEPA, 1991), the MOS can be incorporated into the TMDL using one of two methods:

- Implicitly incorporating the MOS using conservative model assumptions to develop allocations.
- Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The MOS was implicitly incorporated into this Loading Allocation.

The IRW model does have an implicit, unquantifiable MOS largely because it has a tendency to somewhat (or slightly) over-predict PO4 and TP concentrations at most calibration sites (based on the published plots). Therefore, any Baseline condition would have somewhat higher TP loads than might be expected. As a result, any needed reduction to meet a TMDL would tend to be higher than really warranted leading to 'better' water quality, i.e., lower final TP concentrations and loads, than would be required if the model was more 'exact' in its TP predictions.

Following the approach adopted for the Tenkiller Ferry Lake TMDL for the Margin of Safety, the TMDL determined for Tenkiller Ferry Lake accounts for an implicit Margin of Safety (MOS) based on a conservative assumption for derivation of more stringent numeric water quality targets for chlorophyll-*a* and dissolved oxygen. Using a 10% MOS for chlorophyll-*a*, the water quality target is decreased from 10 µg/L to 9 µg/L. Under the revised criteria for the anoxic portion of the water column, OWRB (2014) determined that no more than 70% of the water column for a sampling site shall be less than the cutoff DO concentration of 2 mg/L. Using a 10% MOS for the anoxic water column criteria, an implicit MOS is incorporated in the TMDL analysis with an adopted target of no more than 63% of the water column <2 mg/L.

Adoption of a 10% MOS for more stringent targets for chlorophyll-*a* and the anoxic percentage of the water column will ensure an adequate implicit Margin of Safety (MOS) for the determination of load allocations (LA) for Tenkiller Ferry Lake.

5.6. TMDL Calculations

A TMDL is expressed as the sum of all WLAs (point source loads), LAs (nonpoint source loads), and an appropriate MOS. This definition can be expressed by the following equation:

$$TMDL = \Sigma\ WLA + \Sigma\ LA + MOS$$

Load reduction scenario simulations were run using the linked watershed (HSPF) and lake (EFDC) models to calculate annual average TOC, phosphorus and nitrogen loads (in kg/yr) that, if achieved, should improve dissolved oxygen concentrations and decrease chlorophyll-*a* to meet the water quality targets for Tenkiller Ferry Lake. Given that mass transport, assimilation, and dynamics of TOC and nutrients vary both temporally and spatially, pollutant loading to Tenkiller Ferry Lake from a practical perspective must be managed on a long-term basis with loads expressed typically as pounds or kilograms per year. However, a court decision (*Friends of the Earth, Inc. v. EPA, et al.,* often referred to as the Anacostia Decision) states that TMDLs must include a daily load expression (Grumbles, 2006). It is important to recognize that the dissolved oxygen and chlorophyll-*a* response to nutrient loading in Tenkiller Ferry Lake is affected by many factors such as: internal lake nutrient loading, hypolimnetic oxygen depletion, water residence time, wind action, resuspension and the interaction between light penetration, nutrients, suspended solids and algal response. As such, it is important to note that expressing this TMDL on a daily basis does not imply that a daily response to a daily load from the watershed is practical from an implementation perspective.

Three documents available from EPA provide a statistical basis for the determination of a daily loading rate from an annual loading rate. "*Options for Expressing Daily Loads in TMDLs*" was published by EPA (2007) in response to the Anacostia Decision discussed above. The statistical basis for the calculation of a daily loading rate from an annual load was previously documented by EPA (1991b) in *"Technical Support Document for Water Quality-Based Toxics Control"* and EPA (1984) in "*Technical Guidance Manual for Performing Wasteload Allocations,* *Book VII: Permit Averaging Periods*". These documents provide the statistical methods for identifying a maximum daily limit based on a long-term average and considering temporal variability in the load time series dataset.

The methodology for the MDL is based on calculations of the (a) long-term average load (LTA) of untransformed pollutant loading data calculated with data derived from NPDES wastewater dischargers and the watershed (HSPF) model; and (b) an estimation of the statistical variability of the time series for untransformed loading data based on calculations of the mean (μ), standard deviation (σ), variance (σ^2) and the coefficient of variation (CV). The CV, a measure of variability of the loading data, is computed as the ratio of the standard deviation (σ) to the mean (μ). Based on the long-term average annual loading rate (LTA) required to attain compliance with water quality standards, the maximum daily load (MDL) is determined to represent the allowable upper limit of loading data that is consistent with the long-term average load (LTA) determined by the TMDL study. The allowable upper limit takes into account temporal variability of the PS and NPS loading data, the desired confidence interval of the upper bound for the MDL determination and the assumption that loading data can be described with a lognormal distribution. Appendix D of EPA (1991b) and Section 2 of EPA (1984) present the rationale and derivation of the equations based on the lognormal distribution used to determine the maximum daily load. The MDL is computed from the LTA and the probability-based statistics of the lognormally distributed pollutant loading data by the following equations as:

$+1)$

Where:

MDL = Maximum daily load limit (as kg/day)

E_x = Expected average value of existing load computed from log transformed load data

%R = Required reduction rate for load scenario (%) to meet water quality targets

LTA = Long-term average load based on required reduction scenario (as kg/day)

= Z-score for probability for upper percentile limit of standard normal distribution

= Standard deviation computed from log transformed load data

= Variance computed from log transformed load data

= Coefficient of variation based on untransformed load data

x

s_x = standard deviation of untransformed load data

μ_x = mean of untransformed load data

The equations used for calculating the Maximum Daily Load (MDL) from the Long Term Average (LTA) load are based on the assumption that streamflow, water quality, wastewater effluent and watershed loading data are lognormally distributed. It is well documented in numerous studies that a two-parameter lognormal distribution defined by the mean and variance of the log transformed data set provides a very useful approximation to the probabilistic distribution of streamflow (Nash, 1994; Limbrunner et al., 2000; Vogel et al., 2005). In addition, Van Buren et al., (1997) and Di Toro (1984) determined that water quality analyses based on an assumption of the lognormal probability distribution for effluent, streamflow and water quality concentration are quite realistic for wastewater facilities and many streams and rivers, including waterbodies investigated in the United States.

5.6.1 Load Reduction Scenarios

The procedures for calculating the TMDL were as follows:

1. The Baseline model was run for an 18-year period from 1992 to 2009, to identify the 30-day geomean TP concentrations that needed to be reduced to meet the 0.037 mg/l TP OK Scenic Rivers water quality standard.
2. Subsequently, numerous model scenarios were executed with global (i.e. state-wide) reductions applied to both point and nonpoint sources in order to identify the general level of reduction needed to meet the 0.037 mg/l TP standard as the 30-day geomean concentration. The scenarios were checked to determine whether or not the standard was met at both the AR/OK stateline (reach 630) and numerous mainstem sites on the Illinois River down to the final stream reach (Reach 890) into Tenkiller Ferry Lake.

   Table 5.x shows the results of the Baseline scenario and 4 additional scenarios that were executed in order to idenity the minimum level of reduction in each State needed to meet the standard at the compliance points. The reach locations are shown in the leftmost columns, followed by the Baseline scenario, and then the following four scenarios that were executed:

   a. Global reduction of 72% of all point and nonpoint sources for both States.
   b. A 72% reduction for AR and 99% reduction for OK
   c. A 83% reduction for AR and 99% reduction for OK
   d. A 69% reduction for AR and 93% reduction for OK with bed P concentrations also reduced by these amounts for the respective states.
   e. A 69% reduction for AR and 93% reduction for OK, 90% reduction for Flint Creek watershed, and 71% reduction for Baron Fork watershed with bed P concentrations also reduced by these amounts for the respective states. Point sources loads were reduced by 93% to 98%.

   The sequential execution of these scenarios identified that bed P concentrations were becoming a more significant source of water column TO concentrations as the other sources were reduced. Consequently, in the final scenario we reduced the bed concentrations in each state by the same reductions as the sources.

3. From Step 2, the scenario with a 69% reduction in all sources for AR, and a 93% reduction for OK, along with reduced bed concentrations produced compliance with the 0.037 mg/l TP standard at all sites leading into Tenkiller Ferry Lake. The daily loads calculated for this scenario at Reach 630 were 33.9 lb/day TP, and at Reach 870, the daily load was 3,303 lb/day TP. It should be noted that the compliance time period (period when the standard is just met) occurred during the 2005-06 dry period (i.e., December 2005) for the Stateline site, whereas the corresponding time period for the downstream site (Reach 870) occurred in May 1999 during moderate-to-high spring flows.
4. Mean annual loads were then generated for the 69% AR and 93% OK reduction scenario, and the 18-year mean annual load was divided by 365.25 to determine the average daily load at all sites of interest. This produced a TMDL of 291.5 lb/day TP at Reach 630 and 378 lb/day TP at Reach 870. These values are shown in Table 5.y

along with TMDL values for other impaired reaches, such as Baron Fork and Flint Creek whose TMDL values were developed in the same manner as described above.

5. These daily values were then distributed into the TMDL components as follows:

    a. The annual load allocation provided the WLA component for point sources.
    b. The LA was determined by difference, i.e., LA = TMDL – WLA – FG, where FG was estimated as 0.1% of the TMDL.

6. The same calculations were performed at each of the terminal pour points for the other impaired waterbodies in OK, as defined on the 2012 303d list.

Table 5.2 Comparison of Model Results for the Baseline and Multiple Loading Reduction Scenarios

Location Info			Baseline			72% Global Reduction			72% AR Reduction and 99% OK Reduction			83% AR Reduction and 99% OK Reduction			FINAL TMDL Scenario (Reduced bed P concentrations with 69% AR Reduction, 93% OK Reduction)		
DSN ID	Reach Number/Location	State	Concentration (mg/l)	Number of Violations	Percent Violations	Concentration (mg/l)	Number of Violations	Percent Violations	Concentration (mg/l)	Number of Violations	Percent Violations	Concentration (mg/l)	Number of Violations	Percent Violations	Concentration (mg/l)	Number of Violations	Percent Violations
6320	630[1]	AR	0.119	6521	99.6	0.037	0	0	0.037	0	0	0.036	0	0	0.037	0	0
9635	635	OK	0.119	6521	99.6	0.037	0	0	0.037	0	0	0.026	0	0	0.037	0	0
9637	637	OK	0.121	6500	99.3	0.038	1	0.0153	0.037	0	0	0.026	0	0	0.036	0	0
6420	640	OK	0.121	6503	99.3	0.038	2	0.0306	0.038	1	0	0.026	0	0	0.036	0	0
9650	650	OK	0.123	6499	99.3	0.039	3	0.0458	0.038	1	0	0.027	0	0	0.036	0	0
9660	660	OK	0.129	6514	99.5	0.042	8	0.1	0.039	3	0	0.027	0	0	0.036	0	0
9670	670	OK	0.133	6505	99.4	0.043	16	0.2	0.039	3	0	0.028	0	0	0.036	0	0
9800	800	OK	0.144	6535	99.8	0.047	56	0.9	0.038	3	0	0.028	0	0	0.036	0	0
9810	810	OK	0.145	6535	99.8	0.047	56	0.9	0.039	3	0	0.028	0	0	0.036	0	0
9820	820	OK	0.146	6535	99.8	0.047	56	0.9	0.038	1	0	0.028	0	0	0.036	0	0
9830	830	OK	0.147	6535	99.8	0.049	65	1	0.039	3	0	0.028	0	0	0.036	0	0
9840	840	OK	0.15	6534	99.8	0.049	70	1.1	0.039	2	0	0.029	0	0	0.036	0	0
9850	850	OK	0.153	6534	99.8	0.051	88	1.3	0.039	2	0	0.029	0	0	0.036	0	0
9860	860	OK	0.159	6538	99.9	0.056	193	2.9	0.043	16	0.2	0.03	0	0	0.036	0	0
8690	870[2]	OK	0.165	6538	99.9	0.058	224	3.4	0.044	19	0.3	0.034	0	0	0.037	0	0
9880	880	OK	0.17	6539	99.9	0.06	285	4.4	0.045	30	0.5	0.035	0	0	0.037	0	0

[1] - Illinois River at State Line, [2] - Illinois River at Tahlequah

5.6.1 Illinois River Watershed Load Allocation and TMDL Summary

The resulting allocations by impaired segments are shown in **Table 5.3**. The daily expression of the TMDL is also provided in **Table 5.4**.

Table 5.3 TMDLs for Selected Reaches within the IRW

TMDL Reach (Segment)	TMDL	WLA	LA	FG	MOS
RCHRES 512 - Flint Creek (OK121700060080_00)	9.2	0.5	8.8	0.01	Implicit
RCHRES 523 - Flint Creek (OK121700060010_00)	27.6	0.6	26.9	0.03	Implicit
RCHRES 524 - Flint Creek (OK121700030290_00)	27.9	0.6	27.3	0.03	Implicit
RCHRES 630 - Illinois River (Stateline)	291.3	18.8	272.2	0.29	Implicit
RCHRES 650 - Illinois River (OK121700030350_00)	317.9	18.7	298.9	0.32	Implicit
RCHRES 752 - Baron Fork (OK121700050010_00)	180.9	0.6	180.2	0.18	Implicit
RCHRES 800 - Illinois River (OK121700030280_00)	351.6	19.3	332.0	0.35	Implicit
RCHRES 870 - Illinois River (OK121700030080_00)	359.4	19.3	339.8	0.36	Implicit
RCHRES 890 - Illinois River (OK121700030010_00)	363.6	19.8	343.4	0.36	Implicit

Table 5.4 Daily Expressions of TMDLs for Selected Reaches within the IRW

TMDL Reach (Segment)	TMDL	WLA	LA	FG	MOS
RCHRES 512 - Flint Creek (OK121700060080_00)	30.7	1.6	29.1	0.03	Implicit
RCHRES 523 - Flint Creek (OK121700060010_00)	95.8	2.3	93.4	0.10	Implicit
RCHRES 524 - Flint Creek (OK121700030290_00)	97.4	2.3	95.0	0.10	Implicit
RCHRES 630 - Illinois River (Stateline)	1059.0	68.3	989.6	1.06	Implicit
RCHRES 650 - Illinois River (OK121700030350_00)	1157.6	68.2	1088.3	1.16	Implicit
RCHRES 752 - Baron Fork (OK121700050010_00)	656.4	2.1	653.6	0.66	Implicit
RCHRES 800 - Illinois River (OK121700030280_00)	1292.1	70.9	1219.8	1.29	Implicit
RCHRES 870 - Illinois River (OK121700030080_00)	1344.7	72.0	1271.3	1.34	Implicit
RCHRES 890 - Illinois River (OK121700030010_00)	1366.9	74.6	1291.0	1.37	Implicit

5.6.1 Lake Tenkiller Allocation and TMDL Summary

Although it is well documented, data are presented to show that the assumption of a lognormal distribution for NPS loading data holds true for Tenkiller Ferry Lake. It is noted that no wastewater point sources directly discharge into the lake. Total Phosphorus (TP) loading data derived from watershed runoff is used as an example to demonstrate that (a) natural log transformed TP data follows a normal distribution and (b) a lognormal distribution for loading data are an appropriate assumption for TMDL determinations for Tenkiller Ferry Lake. As shown in Figure 5-1, a typical bell shaped curve is produced from the log transformed TP load data, indicating a normal distribution of the transformed data set. The probability plot for the log transformed time series of TP data are presented as the natural log of the TP load against the Z-score statistic computed from the percentile ranking of the TP load data (Figure 5-2). The log transformed TP loading data shows an approximate linear relationship (r^2=0.82) with the Z-score statistic confirming the assumption of a lognormal distribution. As flow is common to all loads derived from watershed runoff, TSS, TN and TOC loads also display similar lognormal distributions.

Time series derived from the sum of all the daily loads contributed by Illinois River and each tributary and distributed runoff catchment of the HSPF watershed model were used to compute the mean, standard deviation and the coefficient of variation (CV) of the loads for TN, TP and TOC. The variability of the loading data simulated by the HSPF model was determined using the CV's computed from the daily time series (N=365) of the total load accounted for in 2005 by Illinois River and tributary and distributed runoff loads from the watershed model. Loads from all sources were summed to compute long-term averages of the total mass loading over a 365 day period from January 1 to December 31, 2005. For the Tenkiller Ferry Lake TMDL calculations, a 95% probability level of occurrence was used and the corresponding Z-score statistic was assigned a value of Z=1.645.

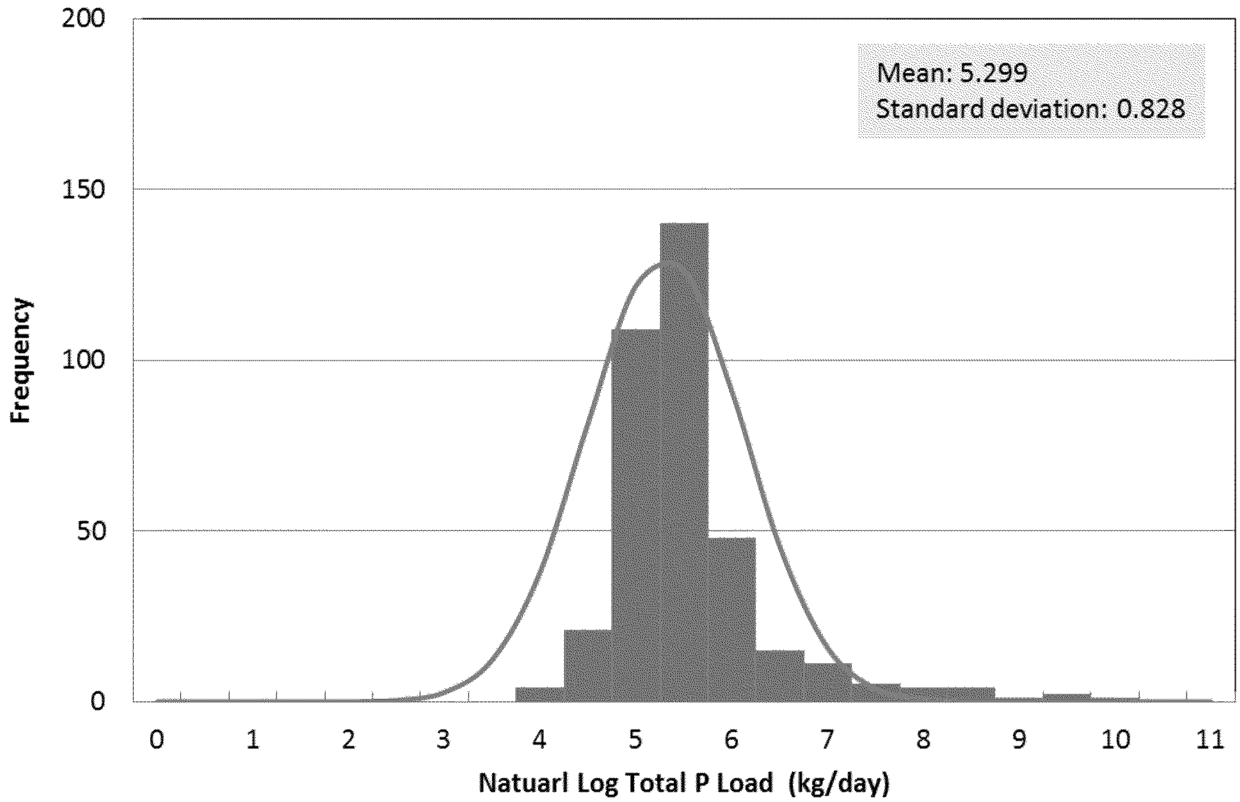


Figure 5.2 Density Distribution of the Log Transformed Total Phosphorus Existing Watershed Loading Data to Tenkiller Ferry Lake

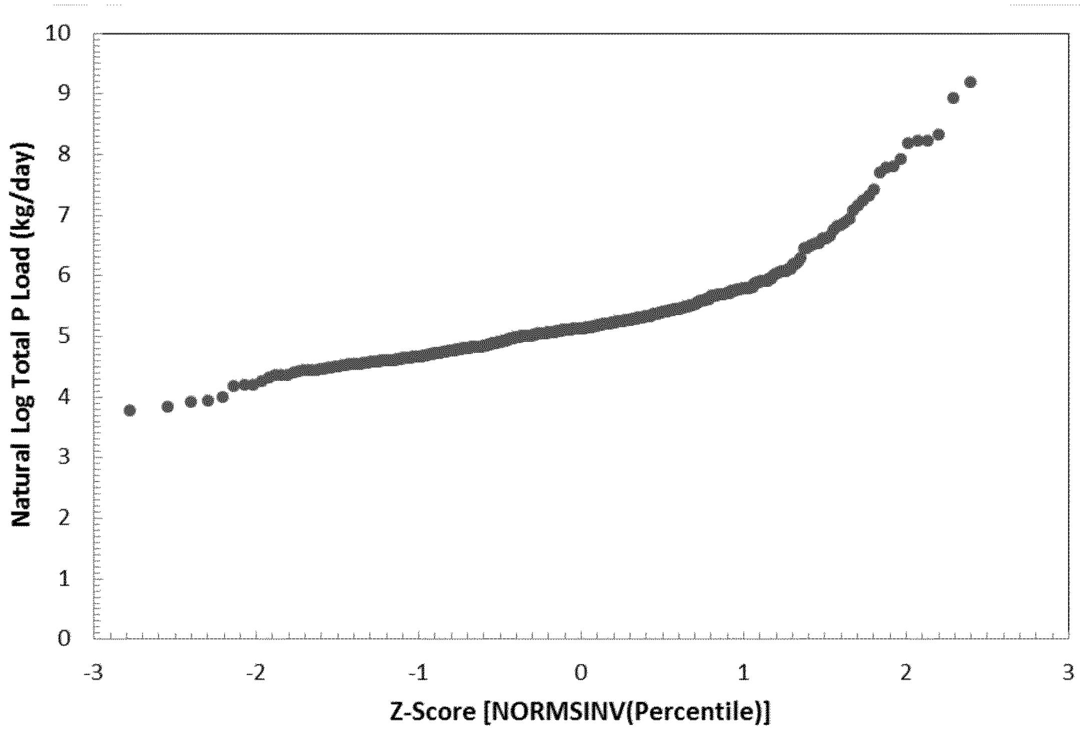


Figure 5.3 Probability Plot of Log Transformed Total Phosphorus Existing Watershed Load to Tenkiller Ferry Lake

The LA for TN, TP, and TOC, determined from the lake model response to load reductions, is based on 72% reduction of the existing 2005 watershed loads estimated with the HSPF model. Load reductions are needed because the criteria for the chlorophyll-a in Illinois River Arm of the lake are not in compliance under the existing loading conditions. Critical conditions for dissolved oxygen at the sampling site near the dam are also not satisfied under the existing loading conditions.

Table 5-1 presents the total load to the lake as the long term average (LTA) load for the existing conditions and for the projected 72% removal management scenario. The LTA load and the coefficient of variation (CV) of the time series external load data is used to compute the MDL for TN, TP, and TOC as presented in Table 5-2.

Since there are no wastewater point sources that directly discharge into the lake, 100% share of the MDL for TN, TP, and TOC is attributed to the watershed (via the LA) which is presented in Table 5-1.

Table 5.4 Long Term Average (LTA) Load for TN, TP, and TOC: Existing Conditions and 72% Removal in Tenkiller Ferry Lake

Water Quality	LTA, Existing	Load	LTA, Reduced	LTA, Reduced
Constituent	Annual	Reduction	Annual	Daily
TenKiller Lake	kg/yr	%	kg/yr	kg/day
Total Nitrogen (TN)	2,231,802	72%	624,905	1,712

Total Phosphorus (TP)	102,896	72%	28,811	79
Total Organic Carbon (TOC)	2,101,332	72%	588,373	1,612

Table 5.5 Maximum Daily Load (MDL) for TN, TP, and TOC to Meet Water Quality Targets for Chlorophyll-*a* and Dissolved Oxygen in Tenkiller Ferry Lake

Water Quality	**LTA, Reduced**	**Load**	**Z-Score**	**MDL**
Constituent	Daily	CV	for 95%	(TMDL) Load
TenKille Lake	kg/day	n=365	Probability	kg/day
Total Nitrogen (TN)	1,712	1.569	1.645	5,754
Total Phosphorus (TP)	79	0.993	1.645	219
Total Organic Carbon (TOC)	1,612	1.432	1.645	5,243
LTA- Long Term Average Load; CV- Coefficient of Variation				

SECTION 6. TMDL IMPLEMENTAION AND MONITORING RECOMMENDATIONS

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. The second step is to develop a TMDL Implementation Plan. The final step is to implement the TMDL Implementation Plan and to monitor stream water quality to determine if water quality standards are being attained.

In accordance with Section 106 of the Federal Clean Water Act and under its own authority, ADEQ has established a comprehensive program for monitoring the quality of the State's surface waters. ADEQ collects surface water samples at various locations, utilizing appropriate sampling methods and procedures for ensuring the quality of the data collected. The objectives of the surface water monitoring program are to determine the quality of the state's surface waters, to develop a long-term data base for long term trend analysis, and to monitor the effectiveness of pollution controls. The data obtained through the surface water monitoring program is used to develop the state's biennial 305(b) report (Water Quality Inventory) and the 303(d) list of impaired waters.

ODEQ will collaborate with a host of other state agencies and local governments working within the boundaries of state and local regulations to target available funding and technical assistance to support implementation of pollution controls and management measures. Various water quality management programs and funding sources will be utilized so that the pollutant reductions as required by these TMDLs can be achieved and water quality can be restored to maintain designated uses. ODEQ's Continuing Planning Process (CPP), required by the CWA §303(e)(3) and 40 CFR 130.5, summarizes Oklahoma's commitments and programs aimed at restoring and protecting water quality throughout the State (DEQ 2012). The CPP can be viewed at ODEQ's website at the following web address: http://www.deq.state.ok.us/wqdnew/305b_303d/Final%20CPP.pdf. Table 5-3 provides a partial list of the State partner agencies DEQ will collaborate with to address point and nonpoint source reduction goals established by TMDLs.

Table 6.1 Partial List of Oklahoma Water Quality Management Agencies

Agency	Web Link
Oklahoma Conservation Commission	http://www.ok.gov/conservation/Agency_Divisions/Water_Quality_Division
Oklahoma Department of Wildlife Conservation	http://www.wildlifedepartment.com/wildlifemgmt.htm
Oklahoma Department of Agriculture, Food, and Forestry	http://www.ag.ok.gov/aems

Oklahoma Water Resources Board	http://www.owrb.state.ok.us/quality/index.php

Point source reductions for this TMDL will be implemented through the NPDES program, which is administered by ADEQ in Arkansas and by ODEQ in Oklahoma.

6.1. Implementation Approach

Remove this?

6.2. Post Implementation Monitoring

EPA guidance recommends that TMDL documentation includes a monitoring plan to determine whether implementation of the TMDL has resulted in attainment of water quality standards and to support any revisions to the TMDL that might be required.

ADEQ and ODEQ will monitor the impaired streams in accordance with their ambient monitoring program in the Illinois River and Tenkiller Ferry Lake. ADEQ and ODEQ will continue to use data from the monitoring stations to evaluate reductions in pollutants and the effectiveness of TMDL implementation in attainment of the general water quality standard. ODEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. ODEQ staff, in cooperation with the Implementation Plan Steering Committee and local stakeholders, will determine the purpose, location, parameters, frequency, and duration of the monitoring. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station. At a minimum, the monitoring station must be representative of the original impaired segment. The Annual Water Monitoring Plan prepared by each ODEQ Regional Office will outline the details of the follow-up monitoring. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. September 30 of each year is the deadline for the recommendations made to the VADEQ regional TMDL coordinator.

To demonstrate that the watershed is meeting water quality standards in watersheds where corrective actions have taken place (whether or not a TMDL or TMDL Implementation Plan has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc.) is bi-monthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one-year period.

6.3. Phosphorous Trading

AR do in terms of regulations – put EPA guidance.

6.4. Reasonable Assurances

EPA guidance about Reasonable Assurance for development of TMDLs states that: A discussion of your reasonable assurances, as defined at 40 CFR § 130.2(p), that wasteload allocations and load allocations will be implemented (http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/TMDL-ch3.cfm).

Reasonable assurance is required by the EPA guidance for a TMDL to be approvable only when a waterbody is impaired by both point and nonpoint sources and where a point source is given a less stringent wasteload allocation based on an assumption that NPS load reductions will occur. In such a case, "reasonable assurance" that the NPS load reductions will actually occur must be demonstrated.

SECTION 7. PUBLIC PARTICIPATION

Public participation is a necessary step in the TMDL development process. Each state must provide for public participation consistent with its own continuing planning process and public participation requirements. When EPA establishes a TMDL, EPA regulations require EPA to publish a notice seeking public comment pursuant to 40 C.F.R. §130.7(d)(2). EPA believes there should be full and meaningful public participation in the TMDL development process. This section describes the public participation for this TMDL development process.

This draft report is submitted to EPA for technical review. After the technical approval, a public notice will be circulated to the local newspapers and/or other publications in the area affected by the TMDLs in this Study Area. The public will have opportunities to review the TMDL report and make written comments during a public comment period that lasts 45 days. Depending on the interest and responses from the public, a public meeting may be held within the watershed affected by the TMDLs in this report. If a public meeting is held, the public will also have opportunities to ask questions and make formal oral comments at the meeting and/or to submit written comments at the public meeting.

All written comments received during the public notice period become a part of the record of these TMDLs. All comments will be considered and the TMDL report will be revised according to the comments, if necessary, prior to the ultimate completion of these TMDLs for submission to EPA for final approval.

After EPA's final approval, each TMDL will be adopted into the Water Quality Management Plan (WQMP). These TMDLs provide a mathematical solution to meet ambient water quality criterion with a given set of facts. The adoption of these TMDLs into the WQMP provides a mechanism to recalculate acceptable loads when information changes in the future. Updates to the WQMP demonstrate compliance with the water quality criterion. The updates to the WQMP are also useful when the water quality criterion changes and the loading scenario is reviewed to ensure that the instream criterion is predicted to be met.

This section of the document will be updated prior to finalization to reflect the public participation during the public comment period.

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APPENDIX A. HSPF WATERSHED MODEL

THE FULL WATERSHED MODELING REPORT DESCRIBING CALIBRAITON AND VALIDATION AND SENSITIVITY ANALYSIS ARE AVAILABLE AT <INSERT THE HYPERLINK FOR THE FILES>

The HSPS model referenced in calibration and validation report for HSPF model for Illinois River Watershed is (MBI, 2015) was modified to include the changes recommended by technical work group. The main changes to the model include:

- The model time span was expanded to 1992-2009 from the calibration span of 2001-2009.
- NACA point source was added to the model.
- The point source loads for the base run (the model that is used as the basis for reduction) are monthly values from 2015 DMR and were applied to each year of the run.
- The land use is changed to NLCD.
- Expert System/hydrology output (COPYs) has been removed from Base run.
- Litter application rates in Base run are set to 2009 values for all years.
- Monthly distribution for litter was updated monthly and the litter applications was set as 10% for surface layer (top 0.3 inches) and 90% for the upper layer (0.3 to 6 inches).
- The RCHRES denitrification rates were updated.

KTAM20 (/hr)	KNO220 (/hr)	KNO320 (/hr)	DENOXT (mg/L)
0.05	0.05	0.05	7.5

- N fertilizer added to non-litter pasture.

APPENDIX B. EFDC HYDRODYNAMIC AND WATER QUALITY MODEL

The revised report for the Lake Tenkiller Ferry EFDC model is available at <Put the link here>

APPENDIX C. ANTI-DEGRADATION POLICIES

STATE OF ARKANSAS ANTIDEGRADATION POLICY

CHAPTER 2: ANTIDEGRADATION POLICY

Reg. 2.201 Existing Uses

Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.

Reg. 2.202 High Quality Waters

Where the quality of the waters exceeds levels necessary to support propagation of fish, shellfish and wildlife and recreation in and on the water, that quality shall be maintained and protected unless the State finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the State of Arkansas' Continuing Planning Process, that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the waters are located. In allowing such degradation or lower water quality, the State shall assure water quality adequate to protect existing uses fully. Further, the State shall assure that (1) there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and (2) that the provisions of the Arkansas Water Quality Management Plan be implemented with regard to nonpoint sources.

Reg. 2.203 Outstanding Resource Waters

Where high quality waters constitute an outstanding state or national resource, such as those waters designated as Extraordinary Resource Waters, Ecologically Sensitive Waterbodies or Natural and Scenic Waterways, those uses and water quality for which the outstanding waterbody was designated shall be protected by (1) water quality controls, (2) maintenance of natural flow regime, (3) protection of instream habitat, and (4) encouragement of land management practices protective of the watershed. It is not the intent of the Extraordinary Resource Waters (ERW) designated use definition to imply that ERW status dictates regulatory authority over private land within the watershed, other than what exists under local, state, or federal law. The Arkansas Natural Resources Commission has responsibility for the regulation of the withdrawal of water from streams and reservoirs, and such withdrawals are not within the jurisdiction of this regulation.

Reg. 2.204 Thermal Discharges

In those cases where potential water quality impairment associated with a thermal discharge is involved, the antidegradation policy and implementing method shall be consistent with Section 316 of the Clean Water Act, 33 U.S.C. § 1326.

Chapter 2: Antidegradation Policy has been approved with the following exception:

- Regulation 2.203 - EPA has determined that it is not obligated to take action under CWA § 303(c) on the agency name revision from "Arkansas Soil and Water Conservation Commission" to "Arkansas Natural Resources Commission."

STATE OF OKLAHOMA ANTIDEGRADATION POLICY

785:45-3-1. Purpose; Antidegradation policy statement

(a) Waters of the state constitute a valuable resource and shall be protected, maintained and improved for the benefit of all the citizens.

(b) It is the policy of the State of Oklahoma to protect all waters of the state from degradation of water quality, as provided in OAC 785:45-3-2 and Subchapter 13 of OAC 785:46.

785:45-3-2. Applications of antidegradation policy

(a) Application to outstanding resource waters (ORW). Certain waters of the State constitute an outstanding resource or have exceptional recreational and/or ecological significance. These waters include streams designated "Scenic River" or "ORW" in Appendix A of this Chapter, and waters of the State located within watersheds of Scenic Rivers. Additionally, these may include waters located within National and State parks, forests, wilderness areas, wildlife management areas, and wildlife refuges, and waters which contain species listed pursuant to the federal Endangered Species Act as described in 785:45-5-25(c)(2)(A) and 785:46-13-6(c). No degradation of water quality shall be allowed in these waters.

(b) Application to high quality waters (HQW). It is recognized that certain waters of the state possess existing water quality which exceeds those levels necessary to support propagation of fishes, shellfishes, wildlife, and recreation in and on the water. These high quality waters shall be maintained and protected.

(c) Application to beneficial uses. No water quality degradation which will interfere with the attainment or maintenance of an existing or designated beneficial use shall be allowed.

(d) Application to improved waters. As the quality of any waters of the State improve, no degradation of such improved waters shall be allowed.

785:46-13-1. Applicability and scope

(a) The rules in this Subchapter provide a framework for implementing the antidegradation policy stated in OAC 785:45-3-2 for all waters of the state. This policy and framework includes three tiers, or levels, of protection.

(b) The three tiers of protection are as follows:

   (1) Tier 1. Attainment or maintenance of an existing or designated beneficial use.

   (2) Tier 2. Maintenance or protection of High Quality Waters and Sensitive Public and Private Water Supply waters.

   (3) Tier 3. No degradation of water quality allowed in Outstanding Resource Waters.

(c) In addition to the three tiers of protection, this Subchapter provides rules to implement the protection of waters in areas listed in Appendix B of OAC 785:45. Although Appendix B areas are not mentioned in OAC 785:45-3-2, the framework for protection of Appendix B areas is similar to the implementation framework for the antidegradation policy.

(d) In circumstances where more than one beneficial use limitation exists for a waterbody, the most protective limitation shall apply. For example, all antidegradation policy implementation rules applicable to Tier 1 waterbodies shall be applicable also to Tier 2 and Tier 3 waterbodies or areas, and implementation rules applicable to Tier 2 waterbodies shall be applicable also to Tier 3 waterbodies.

(e) Publicly owned treatment works may use design flow, mass loadings or concentration, as appropriate, to calculate compliance with the increased loading requirements of this section if those flows, loadings or concentrations were approved by the Oklahoma Department of Environmental Quality as a portion of Oklahoma's Water Quality Management Plan prior to the application of the ORW, HQW or SWS limitation.

785:46-13-2. Definitions

The following words and terms, when used in this Subchapter, shall have the following meaning, unless the context clearly indicates otherwise:

"Specified pollutants" means

(A) Oxygen demanding substances, measured as Carbonaceous Biochemical Oxygen Demand

(CBOD) and/or Biochemical Oxygen Demand (BOD).

(B) Ammonia Nitrogen and/or Total

Organic Nitrogen. (C) Phosphorus.

(D) Total Suspended Solids (TSS).

(E) Such other substances as may be determined by the Oklahoma Water Resources Board or the permitting authority.

785:46-13-3. Tier 1 protection; attainment or maintenance of an existing or designated beneficial use

(a) General.

(1) Beneficial uses which are existing or designated shall be maintained and protected.

(2) The process of issuing permits for discharges to waters of the state is one of several means employed by governmental agencies and affected

persons which are designed to attain or maintain beneficial uses which have been designated for those waters. For example, Subchapters 3, 5, 7, 9 and 11 of this Chapter are rules for the permitting process. As such, the latter Subchapters not only implement numerical and narrative criteria, but also implement Tier 1 of the antidegradation policy.

(b) Thermal pollution. Thermal pollution shall be prohibited in all waters of the state.
Temperatures greater than 52 degrees Centigrade shall constitute thermal pollution and shall be prohibited in all waters of the state.

(c) Prohibition against degradation of improved waters. As the quality of any waters of the state improves, no degradation of such improved waters shall be allowed.

785:46-13-4. Tier 2 protection; maintenance and protection of High Quality Waters and Sensitive Water Supplies

(a) General rules for High Quality Waters. New point source discharges of any pollutant after June
11, 1989, and increased load or concentration of any specified pollutant from any point source discharge existing as of June 11, 1989, shall be prohibited in any waterbody or watershed designated in Appendix A of OAC 785:45 with the limitation "HQW". Any discharge of any pollutant to a waterbody designated "HQW" which would, if it occurred, lower existing water quality shall be prohibited. Provided however, new point source discharges or increased load or concentration of any specified pollutant from a discharge existing as of June 11, 1989, may be approved by the permitting authority in circumstances where the discharger demonstrates to the satisfaction of the permitting authority that such new discharge or increased load or concentration would result in maintaining or improving the level of water quality which exceeds that necessary to support recreation and propagation of fishes, shellfishes, and wildlife in the receiving water.

(b) General rules for Sensitive Public and Private Water Supplies. New point source discharges of any pollutant after June 11, 1989, and increased load of any specified pollutant from any point source discharge existing as of June 11, 1989, shall be prohibited in any waterbody or watershed designated in Appendix A of OAC 785:45 with the limitation "SWS". Any discharge of any pollutant to a waterbody designated "SWS" which would, if it occurred, lower existing water quality shall be prohibited. Provided however, new point source discharges or increased load of any specified pollutant from a discharge existing as of June 11, 1989, may be approved by the permitting authority in circumstances where the discharger demonstrates to the satisfaction of the permitting authority that such new discharge or increased load will result in maintaining or improving the water quality in both the direct receiving water, if designated SWS, and any downstream waterbodies designated SWS.

(c) Stormwater discharges. Regardless of subsections (a) and (b) of this Section, point source discharges of stormwater to waterbodies and watersheds designated "HQW" and "SWS" may be approved by the permitting authority.

(d) Nonpoint source discharges or runoff. Best management practices for control of nonpoint source discharges or runoff should be implemented in watersheds of waterbodies designated "HQW" or "SWS" in Appendix A of OAC 785:45.

785:46-13-5. Tier 3 protection; prohibition against degradation of water quality in outstanding resource waters

(a) General. New point source discharges of any pollutant after June 11, 1989, and increased load of any pollutant from any point source discharge existing as of June 11, 1989, shall be prohibited in any waterbody or watershed designated in Appendix A of OAC 785:45 with the limitation "ORW" and/or "Scenic River", and in any waterbody located within the

watershed of any waterbody designated with the limitation "Scenic River". Any discharge of any pollutant to a waterbody designated "ORW" or "Scenic River" which would, if it occurred, lower existing water quality shall be prohibited.

(b) Stormwater discharges. Regardless of 785:46-13-5(a), point source discharges of stormwater from temporary construction activities to waterbodies and watersheds designated "ORW" and/or "Scenic River" may be permitted by the permitting authority. Regardless of 785:46-13-5(a), discharges of stormwater to waterbodies and watersheds designated "ORW" and/or "Scenic River" from point sources existing as of June 25, 1992, whether or not such stormwater discharges were permitted as point sources prior to June 25, 1992, may be permitted by the permitting authority; provided, however, increased load of any pollutant from such stormwater discharge shall be prohibited.

(c) Nonpoint source discharges or runoff. Best management practices for control of nonpoint source discharges or runoff should be implemented in watersheds of waterbodies designated "ORW" in Appendix A of OAC 785:45, provided, however, that development of conservation plans shall be required in sub-watersheds where discharges or runoff from nonpoint sources are identified as causing or significantly contributing to degradation in a waterbody designated "ORW".

(d) LMFO's. No licensed managed feeding operation (LMFO) established after June 10, 1998 which applies for a new or expanding license from the State Department of Agriculture after March 9, 1998 shall be located...[w]ithin three (3) miles of any designated scenic river area as specified by the Scenic Rivers Act in 82 O.S. Section 1451 and following, or [w]ithin one (1) mile of a waterbody [2:9-210.3(D)] designated in Appendix A of OAC 785:45 as "ORW".

785:46-13-6. Protection for Appendix B areas

(a) General. Appendix B of OAC 785:45 identifies areas in Oklahoma with waters of recreational and/or ecological significance. These areas are divided into Table 1, which includes national and state parks, national forests, wildlife areas, wildlife management areas and wildlife refuges; and Table 2, which includes areas which contain threatened or endangered species listed as such by the federal government pursuant to the federal Endangered Species Act as amended.

(b) Protection for Table 1 areas. New discharges of pollutants after June 11, 1989, or increased loading of pollutants from discharges existing as of June 11, 1989, to waters within the boundaries of areas listed in Table 1 of Appendix B of OAC 785:45 may be approved by the permitting authority under such conditions as ensure that the recreational and ecological significance of these waters will be maintained.

(c) Protection for Table 2 areas. Discharges or other activities associated with those waters within the boundaries listed in Table 2 of Appendix B of OAC 785:45 may be restricted through agreements between appropriate regulatory agencies and the United States Fish and Wildlife Service. Discharges or other activities in such areas shall not substantially disrupt the threatened or endangered species inhabiting the receiving water.

(d) Nonpoint source discharges or runoff. Best management practices for control of nonpoint source discharges or runoff should be implemented in watersheds located within areas listed in Appendix B of OAC 785:45.

APPENDIX D. AMBIENT MONITORING DATA: WATERSHED STATIONS AND LAKE STATIONS